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THE SURFACE TENSION OF WATER ABOVE 100° C.

By Chas. T. Knipp.

THAT the surface tension diminishes more or less regularly with increase of temperature and ultimately vanishes when the critical temperature is reached has been fairly well established by direct experiment in the case of a large number of liquids. The means most available when the pressure is above atmospheric is the familiar capillary tube method. In fact the experimental part of the problem, by this method, presents no difficulties other than those attending high temperature and pressure work. Investigations on water at high temperatures, however, are limited, and this is due, no doubt, to the difficulty of observing the phenomena at these temperatures because of the water vapor attacking the glass.

Frankenheim[1] was the first to study the effect of temperature upon the surface film. He found that the capillary ascent diminishes more rapidly with rise of temperature than the density diminishes. For water he found that if the coefficient of capillarity at 0 degrees C. is 1, the variation with temperature between 0 and 100° C. may be expressed with fair accuracy by the equation,

$$l = 1 - .00191\ t$$

or

$$\gamma = \gamma_0 (1 - .00191\ t)$$

where γ_0 represents the surface tension at 0° C. He was also the first to notice that at certain high temperatures the surface tension

[1] Jour. Prakt. Chem., vol. 23, p. 401.

ceased, and that this temperature was different for different liquids. Brunner[1] in 1847 and Wolf[2] in 1857 found a proportionality between capillary ascent and temperature, but their work was not very accurate. They observed, though, that the proportionality did not always hold. Schiff[3] in 1884 was the next to take up the subject, but his work was limited as the observed heights at only two temperatures, and these were below the boiling point of the liquid. Two years later Eötvos[4] boldly attacked the problem experimentally. He tried 106 different substances; some organic and some inorganic, and also a few liquefied gases. He was not, however, able to go above 210° C. in the case of water because of the water vapor attacking the glass. In 1893 Ramsay and Shields[5] made a very exhaustive study of a number of liquids up to their respctive critical temperatures. For the reason before stated they were not able to make observations with water. The same year E. C. de Vries[6] worked with ether. Its low critical temperature (193°.5 C.) made it possible to use wide barometer tubing for his containing tube. The tube was 8.3 mm. in diameter. The capillary tube was placed in the center and the whole connected with the pressure apparatus and exhausted of air. As a means of heating he used the chemist's method, *i. e.*, heated various liquids whose boiling points differ. His range of temperature was from −102 to 160° C. The variations through small ranges of temperature have been investigated by P. Volkmann,[7] H. Sentis,[8] and V. Monti.[9] J. Verschafflet[10] worked mostly with carbonic acid. The capillary tube method was used. The containing vessel was connected to the pressure apparatus by steel capillary tubes, and the heating was effected by flowing water. Pellat[11] announced that the surface tension is a linear function of the absolute temperature.

[1] Pogg. Ann., vol. 70, p. 514.
[2] Ann. Chim. Phys., 3, vol. 49, p. 230.
[3] Annalen, vol. 223, p. 47.
[4] Annalen, vol. 263, p. 448.
[5] Phil. Trans. Roy. Soc., vol. 184 A., pp. 647–673, 1893.
[6] Arch. Neerland, No. 28, 1894–'95.
[7] Annalen, vol. 56, p. 457.
[8] Jour. de Phys., vol. 6, pp. 183–187, 1897.
[9] Nuvo. Cim., 4, 5, pp. 5–27, 186–203, 1897.
[10] Comm. Leiden, No. 28.
[11] C. R., vol. 118, p. 1193, 1894.

From the foregoing it appears that but little has been done in the case of water. Eötvos was able to reach 210°C., which falls short about 150 degrees of the critical temperature. To extend the investigation over this region is the object of the present research.

Apparatus.

As before stated, water vapor attacks glass at high temperatures and pressures, and renders it opaque and unsafe. The exclusion of glass from the apparatus at once multiplies the difficulties, for complete cognizance of what is going on within must be conveyed to the observer by other than direct vision methods. In the present investigation an attempt was made to measure the surface tension indirectly by lifting a vane partly submerged in the liquid. The drag that is experienced when a vane is thus lifted is, for the most part, due to the surface film. That due to viscosity is but a small part, and in the case of water is negligible, as will be shown later. To lift the vane the sucking action of a coil carrying a current was employed. A preliminary test was made before the apparatus proper was constructed.

It is evident that the success of an investigation like this, where it is proposed to determine the surface tension by lifting a vane in an enclosed vessel reached only by electrical circuits and both vessel and circuits being subjected to a wide range of temperature and pressure, depends in a large measure, if not entirely, on the delicacy yet strength of the apparatus. For this reason considerable time will be given to a description of the same.

A coil *mn* (Fig. 1) of No. 16 copper wire, consisting of two layers of about ten turns each, was supported in a wooden block *bb*. The inside diameter of the coil was 5 mm. The core was made of iron and copper wire, the part *de* of No. 21 iron wire, and *dc* of No. 24 copper wire. This core was supported at the center of the coil by the conical cup at *e* and the guide *g* at the upper end. To avoid friction as much as possible, the hole through *g* was made about double the diameter of the copper wire, and a

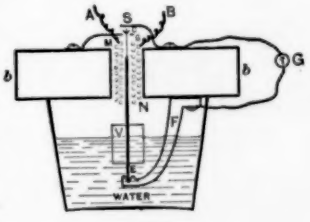

Fig. 1.

conical washer stamped out of copper foil was soldered to *cd*. The height of the guide *g* was adjusted so that the core *ce* occupied the axial position of the coil. Thus when the core was lifted it would always drop back to its former central position. A stop *s* was placed above the top of the core. A mica vane *v*, 1 x 1.5 cm., was fastened to the core just below the coil. The apparatus was placed over a beaker, the water in which came about half way up the vane, as shown in the figure.

The apparatus thus set up, a current was passed through the coil *mn*, which, by adjusting the resistance in the circuit, was increased until the vane just lifted. An ammeter in the circuit gave the value of the current. Before taking each reading the vane was wetted by lowering slightly then raising. The following values of the current required were obtained:

To lift vane in water at 19° C.,	5.8	amp.
	5.9	"
Average,	5.85	amp.
To lift vane in air,	4.35	amp.
	4.4	"
Average,	4.37	amp.

The range was 1.48 amperes.

These results were considered quite satisfactory, the range was amply sufficient to arrange for accurate readings, and these readings were, to within the errors of observation, consistent among themselves. However, the above alone hardly guaranteed that the method would be a success. Working in the open air with the apparatus in full view was no assurance that it would work enclosed in a steel vessel and under varying temperature and pressure conditions.

To this end the preliminary apparatus (Fig. 1) was rebuilt, made smaller and more compact so as to work in a space whose walls could be made strong enough to withstand from 200 to 300 atmospheres pressure without making the vessel unduly heavy and cumbersome. The coil was made of three layers of eleven turns each of the same wire as before. The inside diameter was 4 mm. and length 1.3 cm. The length of the core was 3.5 cm. Instead of

observing by the eye when the vane was lifted, a galvanometer was used as a signal; the circuit was *GfecsG*. The current required to lift the vane in water and air was 4.2 and 2.3 amperes, respectively, giving a range of 1.9 amperes.

The above preliminary tests being sufficiently satisfactory, the apparatus was constructed in its final form. It consisted of a containing vessel in which the water under investigation was placed, and which contained the coil and vane for making surface tension measurements. This vessel, *xy* (Fig. 2), was made of a piece of car axle. The cavity was 7 cm. deep and 3.2 cm. in diameter. To the lower end a small plug, *p'*, made connection with a steel bicycle tube, which in turn connected by a union to the copper capillary tube leading to the pressure gauge and pump. The upper end of the containing vessel was closed by a large plug, *pp*, which screwed home on an annealed copper washer placed on the shoulder *ww*.

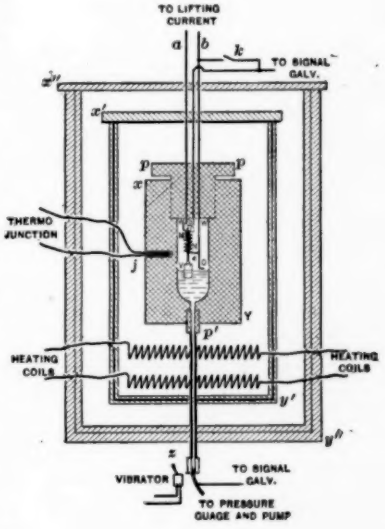

Fig. 2.

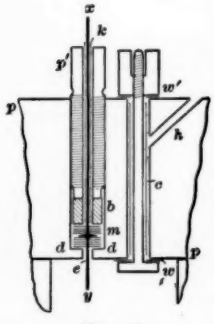

Fig. 3.

Three insulated circuits were run through this plug. This was a difficult task. Two forms of insulated circuits were used. There seems but little choice between them. One may be styled the bolt, and the other the mica disc method. Prof. G. S. Moler, of the department, suggested the former. As will be seen from figure 3, it consisted of a bolt extending through the plug *pp*. A mica collar *c* insulated the bolt from the iron plug. Mica washers, *w* and *w'*, were placed under the head and nut. It was found later that platinum washers placed on either side of the mica washer *w* aided greatly in preventing vapor leaks. The platinum is soft and readily

conforms to any irregularity of the surface as the nut is tightened. A diagonal hole *h* was drilled to act as a vent. This prevented any accumulation of moisture and for this reason this form of circuit remained at all times well insulated, unless moisture condensed on the inner surface of the containing vessel.

The second form, the mica disc method, was more difficult to construct. A half-inch hole was drilled nearly through the plug. The lower end *dd* was reamed out square, and a small hole *e* was drilled on through. Mica discs were stamped out to fit the half-inch hole. A flat head or disc was hammered on a No. 16 copper wire. Two heads thus prepared were soldered together so as to form a straight wire *xy*, the heads forming the disc *m* shown in the figure. A hole that tightly fitted the wire was drilled through the pile of mica discs. Half of these discs were then slipped on one side of the disc *m* and half on the other side. Care was taken to reject all discs that contained radial cracks or seams. The upper end of the half inch hole was threaded out to receive a long finely threaded plug *p'*. A hole through the axis of this plug and lined with mica *k* received the wire *xy*. Between the plug *p'* and the mica discs was placed a thick brass washer *b*, the expansion of which aided in compressing the discs while the vessel was being heated. After each heating the plug *p'* could readily be turned; this, however, was tightened before again heating. This form of circuit has the disadvantage of the pressure within the vessel tending to reduce the pressure on the shoulder *dd* on which the mica discs rest, while in the former the pressure within lessens the chances for a leak. However, the pressure in the opposite direction, due to the plug, was so great in comparison as to cause no serious trouble, yet the circuit at times leaked. One time the leak was traced to one of the discs having a radial crack, which, of course, no amount of pressure would close. On the other hand the latter form of insulated circuit has a decided advantage in that it can be tightened up from time to time and not interfere with the alignment of the apparatus fastened to the wire *y* on the inside of the vessel, while the bolt invariably turned when the nut was tightened which was fatal to the mechanism fastened to it within, and which also ground out the surface of the mica washer, hence when-

ever the bolt circuit leaked (vapor) it caused considerable trouble, but fortunately it leaked less often than the mica disc circuit.

With these precautions regarding the insulated circuits and with the annealed copper washers under the large plug *pp* and small plug *p'*, the vessel (Fig. 2) was enabled to withstand 180 to 200 atmospheres pressure without serious leaks. Later, in several runs, the pressure was pushed up to 240 atms. before the apparatus showed any signs of leaking.

A diagrammatical sketch of the containing vessel *xy*, of the oven, and of the various connections and electrical circuits is given in figure 2. The oven consisted of a sheet iron box, *x'y'*, 8 x 8 x 12 inches. It was lined both inside and outside with one-fourth inch of asbestos. To still further guard against radiation the oven was surrounded with an asbestos lined wooden jacket *x''y''* leaving an air space of about two inches between the two. Windows of heavy glass were placed in the opposite walls of the oven and jacket. The internal apparatus for determining the surface tension is also shown. The lifting coil *mn* was made of the same wire (No. 16) as in the preliminary tests and consisted of two layers of eleven and twelve turns each. The wire was stripped of its insulation and wrapped, in making, on a form so that in the completed coil there was at least .5 mm. of space between the consecutive turns and between the two layers. The ends of the coil connected rigidly to two of the insulated circuits (*a* and *b*) that passed through the large plug *pp*. This formed the lifting circuit.

The lower end of the remaining insulated circuit through the plug terminated in the stop *s* with which the core *ce* made contact when lifted. By closing a key at *k* the water level was adjusted by means of the terminal *o*. These two circuits led to the same galvanometer and were styled the signal circuits, for they acted merely as signals. Obviously, then, a small electrical leak caused but little trouble. Neither was there any appreciable error introduced in case the insulation of the circuit conducting the lifting current was not perfect, for the resistance of the coil was negligible in comparison to that of the insulation.

In the final form the core *ce*, the vane *v*, and the guide *f* were considerably modified (see Fig. 1, then Figs. 4a and 4b). In the

preliminary tests it was found that it would not do to have the core extend below the vane. The core became more or less contaminated, due to oxidization of the iron, because of the difficulty of getting an absolutely perfect platinum plate, and thus the drag due to the surface film was altered. Instead of extending the core some distance below the coil with the vane fastened to the side, it was allowed to extend only a few millimeters below and the vane was suspended from its lower end as shown in figure 4b. A small symmetrical globule was formed on the end of a piece of No. 24 copper wire by heating in a blast flame. This globule was turned down in a jeweler's lathe to the shape *h* with a small point *a* projecting (Fig. 4a). To the point *a* was fused a small platinum wire tip *c* which made contact with the stop *s*. In the preliminary tests the copper and iron wires forming the core were joined by soldering; this, however, would not do since ordinary solder melts at 190 or 200 degrees centigrade. The process was as follows: The iron wire was carefully copper plated. The two were then joined temporarily with solder. The joint was polished and plated with copper for a few minutes, the remainder of the core being protected by beeswax. It was then taken from the bath and heated beyond the melting point of solder which by expansion was forced out through the plate in several places and collected in small globules on the surface. These were brushed away, the surface of the copper polished, and the joint again plated with a heavy coat. The core was now taken from the bath, polished over its entire length and plated with platinum. The vane *v* (Fig. 4a) was of platinum foil rolled down until it was as thin as could well be handled. It was fastened to the lower end of the core by a thin platinum wire as shown at *c*. The average density of the core and vane was 12.24, and its weight was 145 mg. The approximate proportionate amount of copper, iron and platinum in the core and vane was, Cu 38 mg., Fe 57 mg., and Pt 50 mg. The density of the core from these by calculating was 12.2.

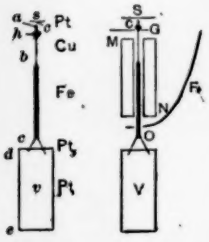

Fig. 4a. Fig. 4b.

Figure 4b shows the guide *g*, the stop *s*, and the form and posi-

tion of the lower guide *f*. In the final arrangement the guide *f* was placed above the vane as before stated. It consisted of platinum wire, the upper end was fastened to the lower face of the large plug, and the lower end terminated in a loop through which the core passed. In taking readings care was taken to have the coil *mn* in a vertical position so that the core hung free of *f* from its upper support *g* (Fig. 4b). It is understood from the drawings and from what has been said that the coil, core, in fact all of the internal mechanism was mounted on the lower face of the large plug. This, of course, was necessary in order to be able to remove the plug from its seat in the containing vessel, and, if desired, to make observations at atmospheric pressure and ordinary temperatures.

The interior of the containing vessel and the apparatus within was plated with platinum on copper. This included the annealed copper washers under the two plugs. A platinum surface resists best the action of the water vapor and does not oxidize. The plating was done according to approved formulæ.[1] To place a continuous deposit on the interior of the containing vessel and the steel tube immediately below required the greatest care and patience. The tube plated was 22 cm. long by 3 mm. internal diameter. Several attempts were made before a successful deposit was obtained. The method shown in figure 5 was quite successful. After thoroughly polishing the interior of the tube it was mounted in a vertical position. The upper end connected to the vessel *mn* made of a large flat cork fitted into an argand lamp chimney. A glass tube drawn out and thrust through a cork was fitted into the lower end of the steel tube *b*. This tube was connected to a funnel *x* whose elevation was a foot or more above the vessel *mn*. The electrical connections for plating are shown in the figure. A copper wire *ab* (in the case of copper plating) served as the anode and was stretched taut through the center of the tube. A small

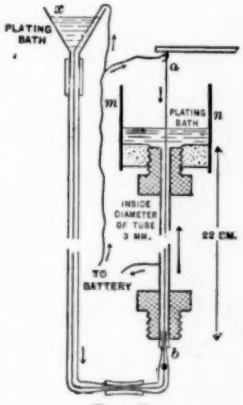

Fig. 5.

[1] Langbein's Treatise on Electro-Plating, 1898.

globule of copper at *b* held the lower end, care being taken not to obstruct the passage. The plating bath was placed in the funnel. The bath thus flowed through the steel tube from the bottom up and collected in the vessel *mn*. The speed of the flowing liquid could be varied at will by raising or lowering the funnel. By this method the gases that collect on the anode and object are rapidly carried to the surface of the liquid as also are any precipitates that may be formed (after the bath has been used for some time) by the action of the current. In fact when the bath was allowed to flow *down* through the tube the interior surface at the lower end of the tube was covered with dark blotches indicating that the circuit was short-circuited by the precipitates collecting. The method just described worked equally well in depositing the platinum plate.

In conducting the experiments four electrical circuits were employed, viz., the lifting, the signal, the temperature, and the heating circuits. The current for lifting the vane was supplied by 15 chloride accumulators. In series with the cells and the lifting coil (Fig. 6) was a 3-ampere fuse, an ammeter *A* reading to 15 amperes, a standard .03-ohm coil of manganin wire, some tin resistance, and a sliding German silver resistance for accurate current adjustment. For the determination of the current flowing in the circuit the fall of potential through the .03-ohm coil was measured by looping around it a Direct Reading Laboratory Standard Weston voltmeter. This instrument read to 150 millivolts. The ammeter served to indicate roughly the amount of current flowing, thus acting as a protection to the millivolt meter. Under these conditions the maximum current was about 5 amperes. To still further guard against accident a fuse was included in the circuit.

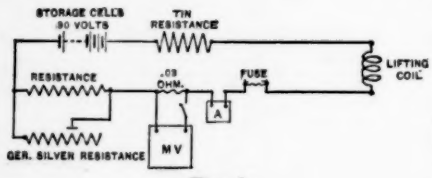

Fig. 6.

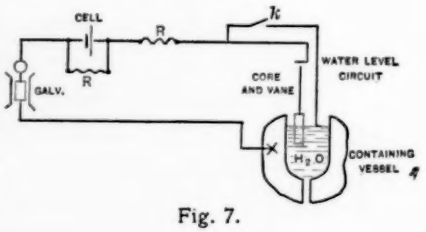

Fig. 7.

The signal circuit consisted of two parts—one to adjust the water

level and the other to know when the vane was lifted (Fig. 7). The circuit comprised a cell properly shunted, a high resistance, and a galvanometer. The water level was adjusted by closing the key *k*.

A copper-platinum thermo-junction placed in a small hole drilled into the side of the containing vessel (Fig. 2, j) was used in determining the temperature. The depth of the hole was 2.6 cm.; the distance of the junction from the interior was 7 mm. Figure 8 shows the electrical connections. The galvanometer used was of the D'Arsonval type. In order to guard against any change in the sensitiveness of the galvanometer its deflections were compared from time to time with certain standard deflections obtained by a Clark cell. This check circuit is shown in the figure.

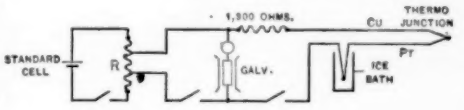

Fig. 8.

Figure 9 shows the electrical connections for heating the oven. The heating coils consisted of iron wire, the degree of heating being readily adjusted by tin resistance frames. Shunted around a portion of the tin resistance was a circuit that contained a vibrator that was an important factor in making observations. Indeed the accuracy of all the readings was due to its use. The vibrator was simply an ordinary door-bell with the bell removed. The hammer was allowed to play on the steel tube that projected beneath the oven. It is shown at *z* in figure 2. A tremor was sent through the containing vessel and all tendency of the core sticking was removed. In fact it was impossible to get consistent readings by means of the signal circuit without this vibrator.

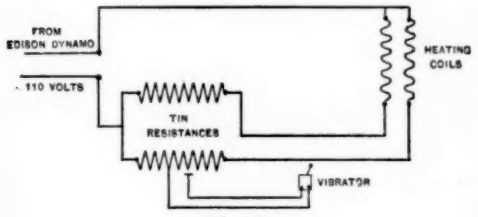

Fig. 9.

Calibrations.

The thermo-junction was calibrated by comparison with a standard 600° C. mercurial thermometer whose zero, steam, and sulphur points were accurately known. The calibration curve that was first

constructed was found to be considerably in error because no correction was made for the stem of the thermometer, or what amounts to the same thing, the stem was not kept at the same temperature as the bulb. A new curve was constructed in which every precaution was taken to avoid the difficulty. Readings for the upper end were made first. The Cu-Pt junction was tied to the bulb of the thermometer and both placed on the interior of the large mass of iron that composed the containing vessel (Fig. 10). A heavy asbestos collar *mn* was placed around that part of the stem that was outside of the oven yet inside of the outer jacket. This collar did not fit tightly on the stem, and allowed the heat from the interior of the oven to circulate up through it. The upper end, however, was tightly packed with asbestos. By this arrangement the lowest reading on the thermometer stem was the 320 degree mark. The heating was conducted very slowly. The temperature and galvanometer deflections were read simultaneously. The galvanometer did not change its sensitiveness, which simplified matters. Readings were also taken while cooling. Care was taken to adjust the rate of cooling to the same as that of heating. The points obtained locate the upper end of the calibration curve (Fig. 11). The lag, as shown by the curve, was negligible.

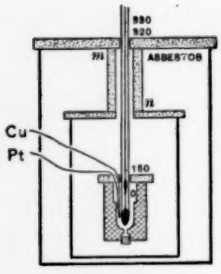

Fig. 10.

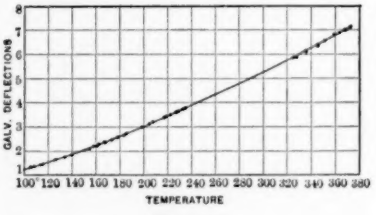

Fig. 11.

The lower end of the curve was next established. To do this the asbestos collar was removed. The containing vessel in the oven and the oven itself were raised so as to allow as much of the stem as possible to protrude. The lowest readable mark on the stem was 150 degrees. A similar set of readings was taken as before. It was thought best not to go higher than 225 degrees in order to avoid the error due to the stem. For temperatures below 150 degrees another thermometer was used whose boiling point was carefully tested. The calibration curve was drawn through these three sets of readings.

The Ducretet pressure gauge was calibrated through the range to be used, *i. e.*, to 225 atmospheres. It was rather suspected that after years of use it would give values too large due to weakening. A manometer tube such as described by Cailletet and Colardeau[1] was made and filled with a known volume of dry air. The volume of the cistern was 42.89 cu. cm., while that of the manometer tube was 668.7 cu. mm. The latter was made of a heavy-walled glass tube of about 1 mm. internal diameter. The upper end of this tube was drawn out into a very fine capillary tube. This was closed after the tube was carefully calibrated and filled with dry air. The error due to disturbing the calibration by sealing the capillary tube was insignificant. The calibration of the gauge was made upon the assumption that Boyle's law is approximately true for air. The piezometer containing the manometer cistern was connected to a high pressure pump. The temperature of the room was 20° C. To guard against a possible error due to the heat generated by the more or less sudden compression of the gas the pressure gauge was read at 2 minute intervals for each elevation until it became constant. The correction curve is shown in figure 12. The lowest reading obtainable on the manometer was that corresponding to a pressure of 70 atmospheres.

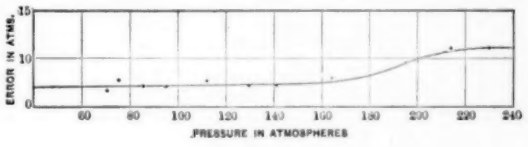

Fig. 12.

I. Pressure-temperature curve of saturated water vapor, and the critical constants.

Before beginning the measurements on surface tension, the apparatus, in a slightly different form, was used in making observations on the vapor tension of water. The object was to reestablish the critical temperature and pressure.

Nadejdine's method enabled him to determine the critical temperature and density, but not the critical pressure. His method was based on the supposition that at the critical temperature the densities of the vapor and liquid are the same. He balanced the tube which

[1] Cailletet and Colardeau C. R., tom. cxii., p. 563, 1891.

was to contain the liquid on a knife edge. Then it was partly filled with the liquid. The tube was no longer in equilibrium. Heat was applied. The balance would be restored under three conditions ; when the liquid is evaporated before the critical temperature is reached, when the liquid expands and fills the vessel, and when the critical temperature is reached before either the liquid expands or is all evaporated. The critical temperature was taken as the highest temperature at which equilibrium was restored, and this was obtained by placing different initial quantities of the liquid in the vessel. The initial volume of the liquid and the volume of the vessel being known the critical density was deduced. Battelli placed the water in a steel tube connected to an open air manometer of reduced height. He observed both the temperature and pressure. Cailletet and Colardeau made, perhaps, the most careful investigation of the constants for water. They also used a steel tube connected to a carefully calibrated hydrogen manometer. Strauss in 1882 determined values for the constants by calculation.

The following table contains the results of different investigators :

TABLE I.

Critical constants.

T	p	δ	Investigator.
358°.1	——	.429	Nadejdine.[1]
364.3	194.6	——	Battelli.[2]
365.	200.5	——	Cailletet and Colardeau.[3]
370.	195.5	.207	Strauss.[4]
365–368	——	——	F. W. D. Dery.[5]

Instead of the large plug *pp* (Fig. 2) another was used having only one insulated circuit running through it. The original intention was to use this circuit in making measurements on the conductivity of different liquids at high temperatures. However, observations along this line have not as yet been attempted as it was desirable

[1] Biebl. 9., p. 721, 1885.
[2] Mem. d. R. Acc. d. Sc., Torino (2) 41, 1890.
[3] C. R., tom. cxii., p. 563, 1891.
[4] J. d. russ. phys.-chem. Ges., 14, 1882.
[5] Bull. Akad. roy. Belg. 29, p. 277, 1895.

not to introduce other liquids into the vessel until the observations on water were completed. The distilled water used was forced through the pump. At first thought this seems undesirable since the water might be more or less contaminated. If it had been possible to construct the containing vessel with its insulated circuit perfectly tight so as not to leak then the necessity of the water going through the pump could have been easily obviated, by some sort of a displacement vessel, but since the leaks were considerable such a vessel constructed within the limits of safety would not be adequate. Hence the only precaution against impurities was by thoroughly cleansing the pump.

The large plug was screwed home. The containing vessel was inverted and filled with distilled water through the lower opening. The steel tube was then firmly screwed in place and it in turn filled with water. In connecting the pump after the containing vessel was put in place care was taken to have the capillary tubes also filled with water. The thermo-junction was then inserted in its proper place, and after all openings in the oven and jackets were closed with asbestos, the heating current was turned on. The rate of heating was such that it required from 7 to 8 hours to heat the vessel from room temperature to 370° C. At this slow rate of heating the temperature lag was not a disturbing factor. The temperatures and pressures were read simultaneously at intervals of 10 to 20 degrees. When the temperature rose to about 110° C., the cock connecting to the pump was slightly opened and about half of the water in the vessel was allowed to be forced out. The first few runs were interrupted by the vessel springing a leak when the temperature rose to about 300° C., the corresponding pressure being 90 atmospheres. However, on several occasions the temperature was carried to 370°, and even to 400° C., without serious leaks. The pressures read from the gauge were corrected, so also were the temperatures whenever rendered necessary by the galvanometer changing its sensitiveness.

Figure 13 shows two tension curves superimposed. The data was taken on different days. They are nearly unique up to the critical point, but beyond that they both take slightly different directions depending on the quantity of water in the vessel before

the critical point was passed. The curve below the critical temperature is independent of the quantity of water in the vessel. The branch *ab* indicates that the vessel was nearly full when the critical

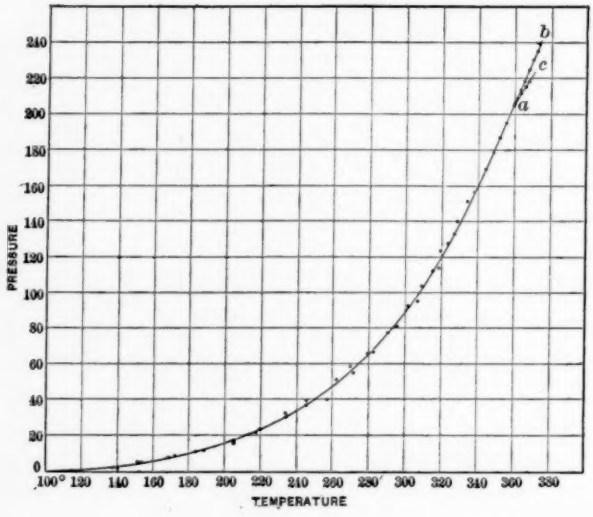

Fig. 13.

point was passed. The quantity of water was less in the case of branch *ac*. Where these two branches intersect is the critical point, and this, as indicated by the curve, is, for the critical temperature 359 degrees centigrade, for the corresponding pressure 205 atmospheres. The data for the curve in figure 13 is given in the following table.

TABLE II.

Temperature.	Pressure.	Temperature.	Pressure.	Temperature.	Pressure.
180°	9.6 atms.	260	47.1 atms.	330°	138.9 atms.
190	12.4 "	270	56.0 "	340	159.8 "
200	15.5 "	280	65.9 "	350	182.2 "
210	19.0 "	290	76.8 "	355	194.0 "
220	23.0 "	300	89.0 "	359	205.0 "
230	27.8 "	310	103.2 "		
240	33.6 "	320	120.0 "		
250	39.9 "				

In another run the resulting curve was found to branch at a lower point, viz: 358°.5 C., and 204 atmospheres.

These results do not exactly agree with those that have been obtained by others, though, no doubt, they represent the critical point with a fair degree of accuracy.

II. Surface Tension.

In order to express the surface tension in absolute units with any degree of accuracy, the relation between the lifting current and the weight lifted should be linear. If the relation is not a linear one the instrument must be calibrated by liquids whose surface tensions at given temperatures are definitely known. Before attempting such a calibration the relation above mentioned was investigated experimentally.

The plug, *pp* (Fig. 2), was mounted on a suitable support, the lifting and signal circuits and also the vibrator being properly connected. The value of the current that was required to lift the system in air was observed. Known weights were added and the corresponding current noted. Table III. gives the data obtained. The resulting curve (Fig. 14) is a straight line. That the relation was linear was fortunate, as it simplified matters. This, no doubt, was due to the fact that the core scarcely moved from its axial position in the coil before the signal was given, and also that the core was saturated. The current flowing through the coil was about 5 amperes.

Table III.

Current in Mv.	Weight of system.	Weight added.	Total weight lifted.
96.	145 mgs.	0 mgs.	145 mgs.
100.5	" "	14 "	159 "
104.2	" "	28 "	173 "
113.5	" "	57 "	202 "
117.2	" "	66 "	211 "
123.4	" "	90.5 "	235.5 "
137.	" "	129. "	274. "
146.	" "	160. "	305. "

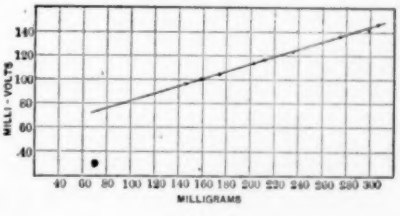

Fig. 14.

The possible effect of the depth of the vane in the liquid upon the current required to lift it was also investigated experimentally. The vane was submerged to five different depths in the water. The electrical connections were the same as before. The lifting of the vane was observed directly by the eye, and then by the signal galvanometer. In using the signal the resistance in the lifting circuit (Fig. 6) was adjusted to make the current larger than necessary. The current was then decreased and its value (by means of the millivoltmeter) was noted the moment that the core broke contact at *s* (Fig. 2), which was indicated by the deflection of the signal galvanometer falling to its zero. This method of using the signal galvanometer in determining the value of the lifting current was used in all the surface-tension readings. The observations tabulated in Table IV. show that the differences between the two methods of observing were no greater than the errors of observation, and consequently that the signal was reliable. It also shows

TABLE IV.

Depth of Vane.	Observed directly by eye.	Observed by signal Galvanometer.		Average.
	mv.	*mv.*	*mv.*	*mv.*
	146.	146.1	145.2	145.7
	145.4	146.2	145.8	145.8
	145.1	145.6	145.3	145.3
	145.8	145.5	146.2	145.5
	145.3	145.6	145.6	145.5]
Average	145.5	145.8	145.6	145.6

that the difference in buoyancy, when the vane was submerged to different depths, was not noticeable; the water displacement due to the volume of the vane was exceedingly small. In the light of the above it would hardly be reasonable to expect an effect due to viscosity.

It is natural to expect a more or less marked temperature effect as the iron core is heated. To test for this the apparatus was placed

in the oven and the heating current turned on. The data obtained was as follows :

TABLE V.

Temperature.	Mv.	Temperature.	Mv.
116°	90.6	231	91.6
156	91.6	283.5	90.8
192.5	90.4	322.5	got no response.

Platting these values (Fig. 15) a straight horizontal line is obtained. Unfortunately the signal refused to respond at the end of last interval, *i. e.*, 322°.5, and further observations could not be taken. A poor contact was found afterwards when the apparatus was taken apart. The data, however, shows no temperature effect. It might be well to state that in the above three investigations different sized platinum vanes were used, hence the results cannot be compared. The data given in Table III. was taken with the vane as last constructed.

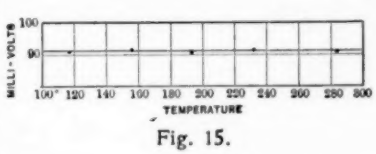

Fig. 15.

Being satisfied that no appreciable error would result from the change in the temperature of the core, from the depth in the water to which the vane was submerged, and that the relation between the current and the weight lifted was linear, the observations on surface tension were begun. The large plug *pp* (Fig. 2) was screwed down tight on its seat in the containing vessel. The cavity was filled with distilled water and connected to the pressure pump as previously described. The different electrical circuits were connected to their proper terminals. The heat was applied very slowly; to heat through the entire range of 360° requiring seven or eight hours.

When the temperature was raised sufficiently part of the water was allowed to flow out by slightly opening for a moment the stop-cock connecting to the pump. It was impossible to determine the water level at *o* (Fig. 2) immediately because the walls of the vessel and the objects within were covered with a film of water. This was known to be the case by the insulation of the signal circuits in part breaking down. The lifting coil acted like a sponge and held a large mass of water which extended to the core and guides *g* and *f*.

It was found that the water would not evaporate sufficiently to make the signal circuits of any use short of 200° C. However this difficulty was overcome by allowing the water to be forced out of the containing vessel but not out of the steel tube immediately below. This caused all of the moisture in the vessel to evaporate in a very few minutes, and the two signal circuits became perfectly insulated. The water was then slowly pumped into the vessel. The circuits remained insulated for some time, when gradually the zero of the galvanometer began to shift, showing that there was a slight accumulation of moisture, however the water level was readily determined. The water level being adjusted, the key *k* (Fig. 2) was opened and the lifting current turned on. Before each reading the vane was wetted by raising then lowering the water. Temperature, pressure, and the current required to lift the same were read simultaneously.

To get consistent readings for the surface tension below 220° C. was quite difficult even when the circuits were almost perfectly insulated. The values were generally small. However, when moisture was condensed on the coil, core, etc., as indicated by the signal circuits, the readings were generally large. When the behavior of the circuits became too erratic it was taken as an indication that the coil, core, and the guides *g* and *f* were enveloped in moisture. This was always overcome by evaporating the moisture as described above, when the readings would return to their former more or less irregular small values. But as the heating was pushed farther a steady condition set in that was remarkable. Not only did the current, required to lift the vane, steadily decrease, but the two signal circuits became better insulated. Above 240° C. there was no trouble whatever of moisture condensing; however the chances for leaks were greater. The vessel leaking proved a great source of trouble. When they were slight the observations were continued by pumping in water, but more frequently the work was interrupted permanently. The high temperature of the apparatus prevented further work that day. Before attempting another run all plugs were tightened and circuits examined. By the vessel leaking a ready opportunity was afforded for taking readings of the current required to lift the system *in* the *vapor*. These values, obviously,

give an indication of the density of the vapor and may be styled base line readings.

Seven runs were made for the purpose of getting surface-tension readings, though each contained a number of values taken in the water vapor. One run was made solely to obtain values of the lifting current with the system in the vapor, *i. e.*, to establish the base line. To be sure that the vapor was saturated the water was let out until the pressure began to drop. It was then pumped in and the pressure rose to a certain value and remained constant on further pumping. In order for the vane to swing free of the water the pumping was stopped soon after the pressure became constant. Since the pressure is determined by the temperature the amount of water in the vessel was immaterial. Table VI. contains data relative

TABLE VI.

Number of readings.

Order of run.	In liquid.	In vapor.	Vessel began leaking at	Permanently interrupted at
1	15	3	347°	357.8
2	14	—	324	337.
3	15	—	—	305.
4	17	—	cooled from	323.
5	9	2	334	340.5
6	23 (?)	6 (?)	—	363.8
7	7	4	—	342.
8	0	13	—	368.

to the eight runs. The order is that in which they were made. The 17 readings in the fourth run were taken while the vessel was cooling down from 323° C. These readings agree very closely (Fig. 16) with the curve obtained on heating. This shows again that the lag was inappreciable. The figure shows a portion of the upper end of the curve where the greatest lag would be expected.

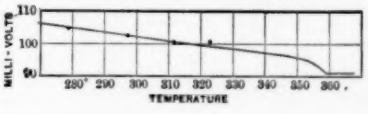

Fig. 16.

The data suggested by Table VI. was divided into groups, each group forming a new point. The points thus formed are shown in

curve *a*, figure 17. The data for the readings in the vapor is represented by the curve *b*. This curve or base line is not horizontal, but drops as the density of the vapor increases. The form of the

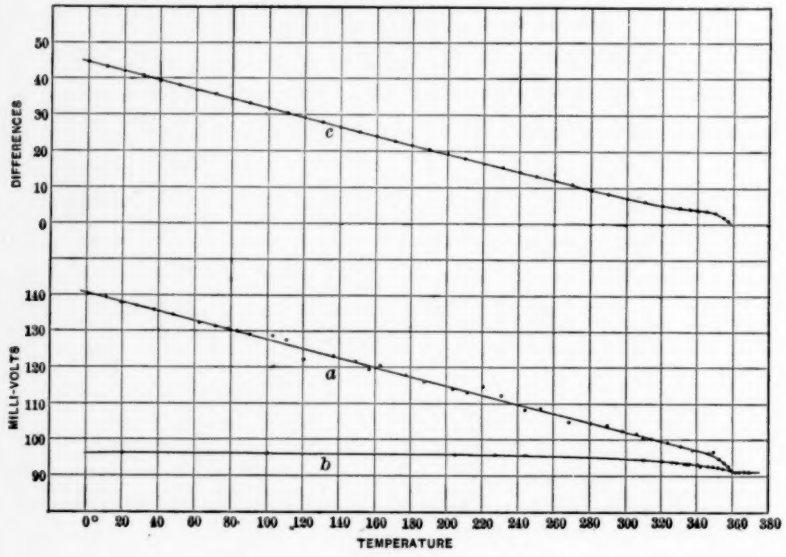

Fig. 17.

curve indicates that the density of the vapor increases very rapidly as the critical temperature is reached, and becomes constant when that point is passed.

To aid in the further discussion of the surface tension curve it was extended back to 0° C. The arrangement of the apparatus for obtaining data for less than 100° C. is shown in figure 18. The water to be investigated was placed in the beaker *mn* surrounded with a large water bath that was constantly agitated. The plug *pp* with all of its electrical connections, including the vibrator, was suitably mounted above the beaker as indicated in the figure. The vane was wetted before each reading by compressing the bulb *b* and forcing water (at the temperature of the bath) from *A* into the beaker. When the

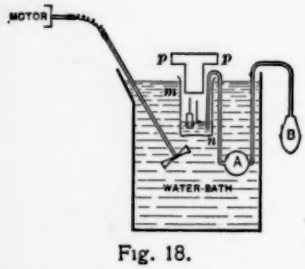

Fig. 18.

bulb was released the original water level was restored. A thermometer was placed in the bath. The data obtained is represented in curve *a* (Fig. 17), and is a straight line as other observers [1] have shown it to be. It will be noticed that the curve continues a straight line on through the boiling point and for some distance above. It was pleasing to have the two curves gotten under such different conditions join so perfectly. This seems to indicate conclusively that the apparatus was capable of giving accurate results, and that the curve above 100 degrees undoubtedly represents the true values of the surface tension.

TABLE VII.

Temperature.	Numbers proportional to surface tension.	Temperature.	Numbers proportional to surface tension.
0	44.2	200	19.3
10	43.2	210	18.2
20	41.7	220	17.
30	40.5	230	15.7
40	39.1	240	14.5
50	37.8	250	13.2
60	36.6	260	12.1
70	35.4	270	10.9
80	34.1	280	9.7
90	32.9	290	8.5
100	31.6	300	7.2
110	30.4	310	6.2
120	29.1	320	5.5
130	27.9	330	4.7
140	26.7	335	4.4
150	25.5	340	4.1
160	24.1	345	3.9
170	23.	350	3.4
180	21.9	352.5	3.
190	20.6	355	2.1
		357.5	1.

The current required to lift the system in air at atmospheric pressure was 96.4 mv., at 200° C., the current required to lift the system in the vapor was 96 mv., at 300° C., 95 mv., and at 360° C., 91 mv. From these values, which are taken from the base line, it is evident that the curve *a* is displaced by an amount equal to the

[1] Landolt and Börnstein, Phys.-Chem. Tables, p. 44.

drop in the base line. In the curve *c* (Fig. 17) temperatures are platted as abscissas and differences (between the curves *a* and *b*) as ordinates. This gives the true form of the curve, the data for which is contained in table VII.

The surface tension can be expressed in any system of units when once its value is known for any given temperature, *i. e.*, if we accept 74.22 dynes as its value at 20° C., then the surface tension at, say, 200° C. is $19.3 \times 1.78 = 34.35$ dynes.

From the data obtained we infer that the surface tension does not decrease gradually to zero as the critical temperature is reached, but falls rather suddenly. This may seem strange since it has been shown by other investigators[1] that the surface tension curves of such liquids as acetic acid, ethel acetate, etc., approach the axis asymtotically. That the forms of curves *a* and *b* (Fig. 17) are correct there can be but little doubt when the conditions under which the data for them was obtained is considered. It will be remembered that above 240° C. the readings were obtained with great accuracy. The different runs extending over several weeks gave for this region almost exactly the same results. On two different instances the observations were extended beyond 355° C. As was pointed out on page 148 the reading below 240° C. (*i. e.*, from 100° –240° C.) were subjected to two disturbances. The one was due to the condensing of moisture on the different parts within, and which caused the values obtained for the surface tension to be large; the other effect was noticeable when apparently the circuits were well insulated and caused the values to be small and fluctuating. It is evident that the large values in the first instance were due to the increased weight of the system. However the small values in the second instance are not so easily accounted for. It is reasonable to suppose that they were due to impurities in the water and on the vane. These impurities, however, had *no effect* on the surface tension above 240° C. as was before remarked. Therefore they must have been rendered inert or were dissolved by the heat. By the method employed in locating the points (see page 149) in curve *a*, figure 17, it is seen that these two effects have practically no tendency to change the direction of the curve in that region.

[1] Ramsay and Shields, Phil. Trans. Roy. Soc., vol. 184 A., p. 647, 1893.

The same consistency that characterized the upper end of the curve *a* was also true of the base line *b*. The readings for this curve were obtained on five different days, and but one point was located that was not on the curve. The points on the curve *b* are actual observations. The fact that the base line became horizontal is evidence in itself that the critical temperature was passed. It would seem that the water becomes quite compressible as the critical temperature is approached, and that the critical density is greater than is usually given. The density of the saturated vapor at any temperature can be computed by aid of the curves in figures 14 and 17, when the volume of the system (*i. e.*, core and vane) is known. However, further discussion of this method of determining vapor density will be postponed. It is the intention to slightly change the apparatus and make it more suited to this phase of the investigation. By increasing the volume of the displaced vapor the readings can be made more sensitive.

Summary.

The principle employed was that of lifting a platinum vane partly submerged in the water. The lifting force was the sucking action of a coil carrying a current. The coil and core were mounted on the inner face of a large plug that screwed into a steel containing vessel made of a piece of car axle. Insulated electrical circuits were run through the plug which enabled observations on surface tension to be made. The containing vessel was in communication with a pump and a pressure gauge. The interior of the vessel and the apparatus within was platinum plated on copper. A copper-platinum thermo-junction was used in determining the temperature. Both the gauge and the thermo-junction were carefully calibrated. The heating was by the electric current. The position of the junction in the large mass of iron that composed the containing vessel made the temperature lag inappreciable. It was placed in a small hole drilled to within 7 mm. of the inner cavity.

The measurements consisted of two parts, viz,, the determination of the critical constants for water and the determination of the surface tension from 100° C. to the critical temperature. In determining the critical constants another plug was used instead of the

one containing the insulated circuits and surface tension apparatus. Temperatures and pressures were read simultaneously. The critical temperature obtained was 359° C. and the corresponding pressure was 205 atmospheres.

The observations on surface tension were repeated a number of times. Various difficulties were encountered, such as moisture condensing on the interior of the vessel, the joints leaking vapor and as a result the insulation breaking down. The moisture was evaporated by letting out some of the water and thus superheating. Leaks were finally stopped by repeated tightening of the plugs. But little trouble, however, was encountered from condensed moisture above 240° C. The apparatus gave remarkably consistent results above this temperature. The apparatus was also used in getting surface tension values from zero to 100° C. The final curve shows that the decrease in surface tension is gradual except when near the critical temperature where it drops suddenly to zero.

The form of the apparatus also enabled the density of saturated water vapor to be determined by noting indirectly the loss in weight of the system (core and vane) when lifted in the vapor.

This investigation was made under the direction of Professor E. L. Nichols to whom I express my thanks for suggestions made and for the facilities placed at my disposal.

PHYSICAL LABORATORY OF CORNELL UNIVERSITY, June, 1900.

BECQUEREL RAYS, A RESUME.

By Oscar M. Stewart.

THE importance of the subject of Becquerel rays has increased almost beyond expectation during the past year or two. Not content with attributing to Becquerel rays all the properties of X-rays, physicists and chemists have found that these rays also possess properties hitherto attributed to kathode rays alone. In its changed aspect it is believed that work along this line will throw light not only on the subjects of kathode rays and X-rays, but possibly on the constitution of matter itself. It has therefore been thought advisable to bring up to date the résumé given over two years ago in this JOURNAL.[1]

In his earlier work Becquerel thought that he had proven beyond all doubt that the radiations from uranium could be reflected, refracted and polarized. It was upon these experiments that the ultraviolet light theory of Becquerel rays was based. No one, including Becquerel himself, has been able to repeat these decisive experiments, and Becquerel now admits that he was mistaken and probably deceived by the presence of a "secondary" radiation. With this exception all the early work on uranium radiations has been confirmed.

Uranium no longer stands as the only element known to emit of its own accord a persistent radiation, and the name Becquerel rays is now applied to the radiations from a number of substances. Some of these radio-active substances have been found to be elements which were hitherto unknown.

Mme. Sklodowska-Curie[2] in searching for other elements or substances which gave radiations similar to those emitted from uranium, found that the oxide of thorium appeared to emit a radiation even more intense than that from uranium. Electrified bodies were more quickly discharged when brought near thorium oxide than when near uranium. G. C. Schmidt[3] independently discovered the radiant activity of thorium and also found that both the element and its compounds imparted conductivity to gases and affected photographic plates. He failed to find any evidences of polarization but thought that he obtained refraction by glass. Mme. Curie had noticed[4] that pitch blende or uraninite and chal-

[1] PHYSICAL REVIEW, VI., p. 239, April, 1898.
[2] Comptes Rendus, 126, p. 1101.
[3] Wied. Ann. 65, p. 141, 1898.
[4] C. R., 126, p. 1101.

colite (phosphate of copper and uranium) were more active than should be expected from the amount of uranium they contained. In fact they were even more radio-active than uranium itself. This led her to suspect that they contained some material more active than uranium. This seemed more probable when she found that the radiation from natural chalcolite was more intense than that from artificial chalcolite, although they contained the same amount of uranium. After chemical analysis M. and Mme. Curie found that the bismuth compounds obtained from pitch blende were very active. They concluded after examining a large number of elements and substances that they had found as an impurity in the bismuth salts a new element. This element, after Mme. Curie's native country, they called *polonium*. When tested by Demarçay no characteristic lines were observed in its spectrum. But this is also true of uranium, thorium and tantalum, which give innumerable fine lines difficult to recognize. At first only a trace of polonium was found in the bismuth salts. Even this gave a radiation several hundred times as intense as that from uranium. As polonium behaves analytically almost like bismuth, they did not succeed in entirely isolating it from bismuth. The partial separation obtained was by utilizing a difference in solubility and volatilization. For Mme. Curie's researches in magnetism and the discovery of polonium and the radiant activity of thorium the French Academy of Sciences awarded her the *Prix Gegner* of 4000 francs.

Continuing this work on the pitch blende derivatives, M. and Mme. Curie and G. Bémont[1] found that the barium salts obtained from pitch blende contained in small traces another element analytically behaving as barium, but extremely active in its radiant power. Chlorides of this new element[2] were obtained by fractional precipitation from the barium chloride. This barium chloride was extracted from a large quantity, 100 kg., of pitch blend (the residue after the removal of the uranium) obtained from the Austrian government. Although obtained only in very small quantities, a few milligrams, the chloride of this new element, called ***radium***, gave about 900 times the intensity of uranium when measured by the conductivity imparted to air. Later by using still larger quantities of pitch blende, salts of radium were obtained which were still more active. So closely related is the chemical behavior of barium and radium that as yet radium has not been obtained pure, but always in some salt of barium. The proportion of radium in a barium salt may be increased by utilizing the difference in solubility of the two salts. Barium salts are more easily dissolved in pure water or alcohol.

E. Demarçay[3] found that the spectrum of the barium salts containing

[1] C. R., 127, p. 1215.

[2] This element *radium* was independently discovered by Giesel, Physikalische Zeitschrift, 1, p. 16.

[3] C. R., 127, p. 1218 and 129, p. 716.

radium contained quite a number of bright lines hitherto unknown, and that the brightness of these lines increased as salts that were more active were tested. One line ($\lambda = 4627.4$) was the center of a peculiar nebulous band; the other lines were all sharp. The wave-lengths of the brightest of these lines were 3814.7, 4683, 4340.6, 3649.6 and 4826.3.

Using the silver-nitrate reaction Mme. Curie[1] determined the atomic weight of the barium-radium. The radio-active salts gave values ranging from 140 to 145.8 while the inactive barium salts gave 137.7 by the same method. This indicates that the atomic weight of radium is greater than that of barium.

A. Debierne[2] has isolated another substance from pitchblende which is comparable in its radiant power to radium and polonium. Its radiation resembles that from radium, although it is not self-luminous like some radium salts. He has found in *actinium*, as he calls this element, all the properties possessed by radium rays. It resembles thorium in its chemical behavior so closely that he is lead to suspect that the activity of thorium may be due to the presence of actinium in thorium salts.

In most of the work which has been done only very small amounts (a few mg.) of the radium or polonium-containing salts were available. Within the last few months, however, more has been available and masses of a gram or more have been used.

The radiation from the earlier radium salts was about nine hundred times as great as that from uranium, while the polonium salts gave about one-half as much as the radium salts. The salts obtained later gave an intensity 5000 to 50,000 times that from uranium. They would affect a photographic plate in half a minute where uranium required hours. The discharge[3] of electricity by this radiation is comparable to the discharge by a flame and could be detected even when the rays penetrated 4 mm. of brass. The radiation, like X-rays, excites a fluorescence on a barium platinocyanide screen even through thin sheets of aluminum.

The intensity of the radiation from these salts increases[4] for some days or weeks after solidification, the final activity being five or six times the initial. Afterwards the intensity remains practically constant as long as kept free from moisture. The activity of polonium, however, slowly falls off so that in the course of a year a considerable decrease occurs.[5]

Small temperature changes produce little effect on the radiation. Heating the salt will destroy its radiant power, but after a day or so it

[1] C. R., 129, p. 760.

[2] C. R., 129, p. 593 and 130, p. 906, April 2, 1900.

[3] Elster and Geitel, Wied. Ann., 69, p. 83.

[4] Mme. Curie, C. R., 129, p. 760. Giesel, Physik. Ztschr., 1, p. 16, 1899.

[5] Curie, Science Abstracts, p. 465, 1900. Behrendsen, Ann. der Physik., 2, p. 335, 1900.

recovers a large part of it.[1] Behrendsen[2] found by reducing the temperature of radium to that of liquid air, that the intensity was decreased. But on restoring the salt to ordinary temperatures, the radiation was more intense than before.

Usually radium salts give greater intensity of radiation than polonium salts. Giesel obtained, however, a polonium preparation which exceeded the best radium salt which had been prepared up to that time. However, as will be seen later, the radiations from the various sources cannot be accurately compared.

FLUORESCENCE AND PHOSPHORESCENCE.

In general all substances which fluoresce or phosphoresce under the action of X-rays or ultraviolet light are excited by radium and polonium, while those which are excited by visible light are not affected by Becquerel rays. Barry,[3] in testing a large number of substances, particularly the alkaline metals and earths, found that all those that were excited by X-rays were also excited by radium rays and those that were not affected by X-rays were also not affected by radium rays. Becquerel[4] noticed some exceptions to this. A diamond that was not excited by X-rays became quite luminous under the action of radium rays. Calcium sulphide is scarcely affected by X-rays, yet it is by radium rays. Some specimens of fluorite which fluoresced strongly by ultraviolet light became nearly as luminous under the action of radium rays. This fluorite, after an exposure to radium rays, showed a visible phosphorescence for more than twenty-four hours.

Some of the radium salts are self-luminous. Giesel[5] prepared some that without exposure to any source of light, gave a bluish light so bright that one could read by it. This luminosity is probably due to the excitation of a fluorescence of the barium salt in the radium preparation by the rays from the radium. Salts which are not self-luminous give out more intense Becquerel rays than the more luminous salts. This is to be expected, as the rays which produce the fluorescence must be absorbed by the barium salt. Salts freshly prepared gradually change their color. Some crystals prepared by Giesel[6] were at first green, then yellow and at last brown. With the change in color the fluorescence of the salt became weaker and the Becquerel rays stronger.[7]

[1] Elster, Verhandl. Phys. Ges., Leipzig, Jan. 5, 1900.
[2] Ann. der Physik., 2, p. 335, 1900.
[3] C. R., 130, p. 776.
[4] C. R., 129, p. 912.
[5] Physik. Ztschr., 1, p. 16.
[6] Ibid.
[7] Also M. and Mme. Curie, C. R., 129, p. 823.

Giesel[1] found that, like X-rays, radium rays produced a faint sensation of light when brought near the eyes,—even when they were closed. This sensation is probably due to a fluorescence excited within the eye itself.

Some of the Curie polonium preparations do not excite fluorescence although more active in discharging electrified bodies than some of the de Häen preparations that give relatively strong fluorescent action.[2] This indicates a difference in the radiations from different salts which is confirmed in other ways.

Conductivity of Gases.

The radiations from the salts of uranium, thorium, polonium, radium, and actinium impart a temporary conductivity to gases. This conductivity has been studied in detail in the cases of radiations from uranium and thorium by Rutherford[3] and Owens.[4] The conductivity imparted to gases by Becquerel rays does not differ essentially from the conductivity imparted by other methods, as by X-rays, kathode rays, or flames. The results in all cases so far obtained agree with the ionization theory first suggested by Giese[5] and Schuster[6] and later more fully developed by Professor J. J. Thomson. This theory assumes that under the influence of X-rays or Becquerel rays some of the molecules of the gas are broken up into ions, half of which are charged positively and the other negatively. These ions may in some cases become nuclei for clusters of molecules, as in the case of the gases from flames where the ions seem to have greater mass than usual. Under the influence of electrical forces the ions move with a velocity approximately proportional to the intensity of the field. A charged body placed in the gas will therefore attract one kind and repel the other. Upon coming in contact with a metallic conductor these ions will give up their charges and cease to exist as ions. The ratio of the number of ions existing in any gas to the total number possible is very small, so that the gas when ionized by any radiation behaves like an extremely dilute electrolyte. From this it follows that the electrical current between two electrodes immersed in the gas is not always proportional to the difference of potential, that is, it does not obey Ohm's law. For small potential differences, the current will be approximately proportional to the potential difference ; but for much larger potential gradients, all the ions may be used in carrying charges as fast as generated by the rays. Therefore as the cur-

[1] Physik. Ztschr., 1, p. 43, 1899.
[2] Meyer and von Schweidler, Physik. Ztschr., p. 209, February 10, 1900.
[3] Phil Mag., 47, p. 109.
[4] Phil. Mag., 48, p. 360.
[5] Wied Ann., 17, p. 538, 1882 and 38, p 403, 1889.
[6] Proc. Roy. Soc., 37, p. 317, 1884.

rent increases it will approach a limit where for further increase in potential no increase of current will result.

The velocities of the positive and negative ions in various gases have been determined by several different methods. It is almost universally true that the negative has a greater velocity than the positive ion in the same electrical field. In dry air the velocity of the negative ion is about 37 per cent. greater than the velocity of the positive.[1] Rutherford determined the velocity of the ions generated by the radiations of uranium and found that they were, within experimental errors, the same as those generated by X-rays. While the method was not at all accurate for absolute determinations, it afforded a good method for comparison. As in the case of air ionized by X-rays, the negative ion moves faster than the positive ion in the same electrical field. This explains the results obtained by Beattie, who observed that the gas near uranium in an electrical field was generally positively charged. As the positive ions move through the electrical field more slowly than the negative, an excess of positively charged ions will be found in the field.

The ionization produced in a gas is proportional to the absorption of the rays by the gas. It is therefore those rays that are most strongly absorbed that will produce the greatest conductivity in a gas. The absorption of polonium rays by air is greater than the absorption of radium rays, so that for the same intensity polonium rays will produce greater ionization. The discharging action of Becquerel rays from different sources is therefore not a true measure of their intensities. The radiation from these various substances is also known to be non-homogeneous in character. For example, Rutherford has found that the radiation from uranium may be classified in two groups, α and β rays. The α rays produce relatively a greater amount of ionization than the β rays. It is thus seen that any measurements of the relative intensities of Becquerel rays from different sources by the conductivity they impart to the air is liable to considerable error. It may be likened to the measurements of the intensity of the different sources of visible light by a method which really measured the intensity of one color only, as, for example, green. The same objection can be made to photographic or fluorescent methods.

The effect of Becquerel rays on a spark gap has been tested by Elster and Geitel.[2] When a spark gap, 1 cm. long, consisting of a positive knob and a negative disc, was exposed to these rays, the spark or brush discharge was changed into a glow discharge. The spark gap was found to be very sensitive to the presence of the rays. The electrodes did not need to be polished as in the case of ultraviolet light.

[1] Zeleny, Phil. Mag. 46, p. 120; Proc. Roy. Soc. 66, p. 238, March 1, 1900.
[2] Wied. Ann., 69, p. 673.

Absorption.

By measuring the absorption of uranium rays by different numbers of thin plates, Rutherford concluded that uranium rays were not homogeneous, but could be divided into two classes, α rays and β rays. The β rays were much more penetrating than the α rays. Relatively greater ionization is produced by the α rays, as they are more strongly absorbed by gases. The α rays therefore appear to be the more intense, as measured by the conductivity imparted to gases. As a result of this composite character, the absorption of Becquerel rays from uranium does not obey the ordinary law of absorption. A thin sheet of metal or a sheet of paper reduces the intensity considerably, but as the number of layers is increased their relative effect decreases. The first layers absorb the α rays, which apparently are the most intense, and additional layers affect only the β rays, which are more penetrating. Aluminium foil, 0.002 cm. thick, reduced the intensity to about $\frac{1}{2}\frac{1}{0}$ of its original value. But an additional thickness of 0.05 cm. only reduced the intensity to about one-half of the intensity transmitted through 0.002 cm. Rutherford's results indicate that the β rays are homogeneous. Their penetration is comparable to that of X-rays from an ordinary Crookes' tube. X-rays from the modern "hard" tube are however much more penetrating. The α rays have about the same penetrative power that "secondary" X-rays have. Since the α rays are the most active in producing ionization and the β rays have the greatest photographic action, determinations by these two methods of the absorption of uranium rays by different substances give results which do not agree. The α rays appear to come from the surface, while the β rays seem to come from the interior. Thus the radiation from a thin layer consists chiefly of α rays, while the proportion of β rays is increased if the radiation is from a thick layer.

The radiation from thorium[1] is in general more penetrating than uranium rays when measured by the conductivity imparted to gases. Schmidt[2] found that the absorption of thorium rays by a number of layers of metal was less than the sum of the absorption by the layers taken separately. This shows that these rays too are not homogeneous. However Mme. Curie[3] noticed a difference between the radiation from thin and thick layers of the thorium compound. Owens[4] found that the radiation from thin layers was homogeneous, and that the radiation from layers a millimeter or more in thickness was not homogeneous.

Owens showed that the absorption of thorium rays by gases followed the order of the gas densities.

[1] Mme. Curie, C. R., 126, p. 1101 and Rutherford, Phil. Mag. 47, p. 123.
[2] Wied. Ann., 65, p. 141.
[3] C. R., 126, p. 1101.
[4] Phil. Mag., 48, p. 360.

Becquerel[1] observed, while obtaining fluorescence of different substances by radium rays through absorbing screens, that the screens affected the fluorescence in some salts more than it did in others. The simplest explanation of this is that the radiation from radium is also not homogeneous in character. This is confirmed by the researches of Meyer and von Schweidler[2] who found, as in the case of uranium and thorium, that the absorption of radium rays by quite a number of substances did not obey the ordinary absorption law. Using the rate of discharge of an electrified body as a measure of the intensity they found that a thin layer of metal diminished the intensity greatly, but additional layers produced but little effect. Through a thin sheet of platinum, 0.0025 mm. thick, 49 % of the original intensity was transmitted, while two such sheets let through 36 % and a layer, 0.12 mm. thick, gave 15 %. 28 % was transmitted through one sheet of aluminium, 0.16 mm. thick, while 16 % was transmitted through six sheets. A sheet of tin, 0.011 mm. thick, transmitted 44 %, two sheets 31 % and fifteen sheets 15 %. 38 % penetrated one sheet of paper, 0.06 mm. thick, and 20 % twenty-two sheets. Glass of 0.16 mm. thickness, transmitted 26 % and ten plates 16 %. Similar effects were obtained through quite a number of other metals and substances. These results were obtained with the radiation from a radium barium carbonate prepared by M. and Mme. Curie. The rays from a bromide and a chloride of radium prepared by Giesel behaved similarly, but were less penetrating than the rays from the salt obtained from the Curies.

As has been shown, the radiations from uranium, thorium and radium consist of at least two kinds of rays, one which is greatly absorbed and another which is far more penetrating. R. J. Strutt[3] has found that the absorption of the more penetrating component of radium rays depends only on the density and thickness of the absorbing substance. The absorption by various substances, ranging in density from that of platinum, lead and silver, to that of aluminium, paper and sulphur dioxide, follows the same order as their densities. He further showed that within a reasonable approximation, the quotient of the coefficient of absorption divided by the density is a constant. This is the same law observed by Lenard[4] in the case of kathode rays. The absorption however was about five hundred times greater in the case of kathode rays.

Polonium rays seem to correspond to the less penetrating rays of radium, being readily absorbed by all substances. While rays have been obtained[5] from radium which have penetrated 1 to 2 cm. of metal, polonium rays are greatly absorbed by paper and card board. Giesel said that

[1] C. R., 129, p. 912.
[2] Physik. Ztschr., 1, p. 209.
[3] Nature, 61, p. 539, 1900.
[4] Wied. Ann., 56, p. 255.
[5] Giesel, Physik. Ztschr., 1, p. 16.

polonium rays gave better radiographs of the hand as they showed more contrast. However these radiations will probably never be found very useful in surgical work owing to the strong absorption of them by air and light substances. A few centimeters of air will totally absorb the rays from the polonium prepared by M. and Mme. Curie, while rays from radium sufficiently intense to excite a fluorescent screen have been obtained through 40 or 50 cm. of air.

Mme. Curie[1] noticed that the absorption of the rays from their polonium increased as the distance from the source is increased. They will penetrate a very thin aluminium plate, but their penetrative power is decreased thereby. Or as it may be stated, the coefficient of absorption increases with increase of the thickness of the absorbing medium. These rays seem to behave like small projectiles which rapidly lose their velocity and therefore their penetrative power.

Evidence of a feeble but more penetrating radiation from radium closely resembling X-rays has been recently found by Villard.[2]

Chemical Effects.

M. and Mme. Curie[3] found that the glass of bottles in which radium salts had been kept for some time turned violet and then black. The effect seems to gradually penetrate through the glass. Villard[4] noticed the same effects with X-rays. He said that a radiograph can thus be obtained on glass by a sufficiently long exposure to X-rays. This coloring of the glass has also been observed with kathode rays. Giesel[5] found that rock salt or potassium bromide when exposed to radium rays for a day took the same coloring that kathode rays give them. M. and Mme. Curie noticed that a barium platinocyanide screen was fatigued by the impact of radium rays in the same way that it is fatigued by kathode rays. Radium rays act in many ways like light, reducing silver salts, peroxide of iron and bichromate of potash in the presence of organic substances. Besides coloring glass they will also color porcelain and white paper.[6]

The radiation from radium salts seems to convert oxygen into ozone. This was first noticed by Demarçay, to whom M. and Mme. Curie had sent some radium salt in a tightly stoppered bottle. On opening the bottle, the characteristic odor of ozone was distinctly noticeable. A coloring of a mixture of starch and potassium iodide,[7] a common test for

[1] C. R., 130, p. 76.
[2] C. R., 130, pp. 1010 and 1178.
[3] C. R., 129, p. 823.
[4] C. R., Nov. 27, 1899.
[5] Verhandl. Phys. Ges., Leipzig, Jan. 5, 1900.
[6] Science Abstracts, p. 465, 1900.
[7] M. and Mme. Curie, C. R., 129, p. 823.

ozone, was obtained. Giesel, however, failed to detect the formation of ozone by any of the salts he had.

In the course of time the radio-active salts undergo changes of structure. This is quite noticeable in some of the radium barium salts which change color for several days after they are made. A greenish yellow barium platinocyanide screen prepared from barium salts containing radium was observed by Giesel to be at first yellow then orange and finally a brownish red. A single one of these crystals will appear a clear yellow but on crossing two of them only brown red light is transmitted. The same effect is noticed when one of these crystals is tested with a Nicol. The usual barium platinocyanide salts as well as the freshly prepared active salts show no such polarization.

SECONDARY OR INDUCED ACTIVITY.

Sagnac [2] discovered that X-rays had the power of giving to bodies on which the rays impinge the ability to radiate rays which are called "secondary" rays. The action of these secondary rays ceases the instant the X-rays are cut off from the excited substance. As Becquerel rays seemed to be similar in action to X-rays, it was therefore natural to expect such rays in this case. M. and Mme. Curie [3] found that the rays from radium were apparently able to induce in other substances such as zinc, platinum, bismuth and even paper the temporary power of emitting Becquerel rays. These secondary rays were readily detected by the conductivity they imparted to gases even after the removal of the radium. Increasing the length of exposure to radium rays increased the acquired activity. On removal of the radium the induced radiation rapidly decreased, in two or three hours being reduced to about one-tenth. The secondary activity induced in the different substances varied from one to fifty times the intensity of the radiation from uranium. An explanation of this phenomenon is readily suggested. If the radium gives off a vapor or something similar to a fine dust, some of it may be deposited on neighboring substances. Each of these small particles may give off Becquerel rays, but owing to its small size it is unable to keep up this output of energy. However, it was found that the induced activity could not be destroyed by washing. And as the radium rays would produce this effect through thin sheets of aluminium, they felt confident that it could not be due to the presence of a vapor or to traces of the radium salt on the substance. It seemed to be more allied to a phosphorescence. However, if it were a real induced effect, differences should be detected in the activity excited in different bodies, as is the case with secondary

[1] Verhandl. Phys. Ges., Jan. 5, 1900.
[2] C. R., 125, pp. 573 and 942, also 126, p. 521.
[3] C. R., 129, p. 714.

X-rays. But no such difference was observed, all substances apparently showing the effect equally.

Becquerel[1] observed that this activity was induced in pieces of the fluorite which showed such intense phosphorescence. After an exposure to radium rays it was able to discharge electrified bodies. However, the acquired activity could be destroyed by heating or by washing with water. This is contradictory to the results of M. and Mme. Curie. He further found that although this activity, which was acquired by many different substances, could discharge electrified bodies, it could not affect a photographic plate.

Elster and Geitel[2] while freeing some radium salts from water in a vacuum tube found that a cold glass body brought into the tube became coated with a scarcely visible deposit. This glass body was then found to emit rather intense rays. At first they thought that they had a case of the induced activity similar to that announced by M. and Mme. Curie, but they found that this activity could be destroyed by washing. These results of Becquerel and Elster and Geitel, together with the work of Rutherford on thorium, to be referred to later, make it quite probable that some of these salts, in addition to emitting Becquerel rays, send out very small particles, perhaps of molecular dimensions, which retain for a time the ability to give out these rays. Rutherford[3] has in the case of thorium found very strong reasons in support of this view. He has found that these small particles can apparently penetrate screens of paper and thin sheets of metals.

It now seems probable that Becquerel rays are similar in character to kathode rays, that is, are small particles of matter carrying negative charges and moving at a high velocity. By some writers it has been thought necessary to explain the apparent penetration of thin screens of metal by assuming that when a particle strikes one side another particle on the opposite side is in some way driven off. Hence if kathode rays impinge on one side, new rays are emitted on the opposite side, giving the metal screen the appearance of transparency. Following this line, Villard[4] has attempted to show that in the case of radium rays the apparent penetration is due to secondary rays which are emitted by the opposite face. These secondary rays are of an entirely different nature from the induced rays of Curie or Rutherford. They cease the instant the incident radiation is suppressed. Villard thought that he had proven that the chief radiation beyond a screen started from the screen itself going in a path perpendicular to its surface. While under some circumstances the sec-

[1] C. R., 129, p. 912.
[2] Verhandl. Phys. Gesell., Leipzig, Jan. 5, 1900.
[3] Phil. Mag., 49, pp. 1 and 161.
[4] C. R., 130, p. 1010.

ondary emission from screens may be the predominate one Becquerel[1] denies that it is always so. He found evidences that some of the rays passed directly through, accompanied, however, by a diffuse radiation from the screen. With thick screens, or thin ones placed obliquely, the secondary rays are relatively more intense, but for thinner screens they become less important.

The secondary rays may differ from the incident beam, but to what extent is not known. Different observers disagree. Dorn[2] says that the rays from the salt consist chiefly of rays which are not deflected by a magnet but are transformed by a screen into deflectable rays. Villard[3] says that secondary rays are produced by the deflectable rays and always leave the screen perpendicularly. Becquerel thought that part of the secondary rays could not be deflected while the rest could.

THORIUM "EMANATIONS."

Mme. Curie[4] noticed that the radiation of thorium from thick layers was apparently more penetrating than than from thin layers. This was confirmed by Owens[5] who also observed that the radiation from thick layers of thorium was greatly affected by slight air currents. Rutherford[6] has taken up the subject and has found that thick layers, one millimeter or more, of thorium oxide and other thorium compounds seem to have the property of giving off small particles which can radiate Becquerel rays for a time. This vapor or "emanation," as Rutherford calls it, can pass through very thin sheets of metals and through many layers of foolscap paper. It gradually diffuses itself through the air and may be carried away by light currents. When the "emanation" is drawn by a current of air into the space between two metallic plates, one of which is connected to a sensitive electrometer, the intensity of its radiation may be measured by the electrical current which will pass through the gas. It was found by this method that the electrical discharge would last about ten minutes after the air current is stopped. If the conductivity had been due to the ordinary gas ions brought over from the neighborhood of the thorium, it would have lasted for only a second or so. For considerable potential differences, the ions that carry the charges in the conduction in gases, are used and thus destroyed as rapidly as they are produced. Rutherford, however, found that the rather slow decay of the electrical current after the air motion had stopped, was independent of the potential difference employed. This too contradicts the supposition that ions alone were present, for in this case for large potential differ-

[1] C. R , 130, pp. 979 and 1154.
[2] Beiblätter, p. 572, 1900.
[3] C. R., 130, p. 1010.
[4] C. R., 126, p. 1101.
[5] Phil. Mag., 48, p. 360.
[6] Phil. Mag., 49, pp. 1 and 161.

ences the ions would be used up immediately. It seems evident that there must be something in the air between the plates of the condenser which, by sending out Becquerel rays, made the air conducting. Air containing these emanations could be drawn through wool or bubbled through water, dilute or strong sulphuric acid, without destroying the emanations. Ions are destroyed by such processes. The emanation is also independent of the nature or pressure of the gas surrounding the thorium.

Rutherford found that under certain conditions this emanation has the property of making other bodies radio-active. Any substance, charged to a negative potential, will become able to emit Becquerel rays after it has been kept for a few hours near thorium or in contact with air containing the emanation. By keeping a wire exposed to air containing the emanation, negatively charged, the radio-activity may be concentrated on it instead of being distributed over the neighboring surfaces. Bodies made active in this manner will retain this property for several days. Rutherford showed that this induced activity could not be due to the direct radiation of the thorium rays or to any ordinary dust from the thorium.

It seems probable that the small radio-active particles which diffuse from thorium in some way take on a small positive charge. The particles will then be attracted by negatively charged bodies. In this way a body may become partially coated with this active material. It was found that the activity which ordinarily would last for several days could be removed by a long and vigorous polishing with sand paper. On placing a very active platinum wire in sulphuric acid, the radio-activity was largely destroyed. The residue of the acid obtained by boiling it down on a sand bath was then found to be strongly active.

The radiation from the different bodies that had been made active, differed from thorium radiation. It was in some cases more intense, as when the activity was concentrated on a negatively charged wire. It was more penetrating than the radiations from any of the uranium, thorium, polonium, or radium compounds which he had been able to test. If this activity is due to the presence of a radio-active substance, its power per unit mass of emitting Becquerel rays is large as compared to that of thorium.

Debierne[1] has recently found a very active element, actinium, which so closely resembles thorium in its chemical behavior that he thinks the activity of thorium is in part, at least, caused by the presence of this element. He points out that the experiments of Rutherford can be explained by the presence of this element as an impurity.

Rutherford thinks that the reason the vapor particles are attracted by a

[1] C. R., 129, p. 593, and 130, p. 906, April 2, 1900.

negative charge is due to the fact that they become positively charged by the diffusion of the ions in the gas. As negative ions are known to move more rapidly than the positive they tend to leave the gas with an excess of positive ions. M. and Mme. Curie have proven that some radio-active substances tend to become positively charged since negative charges are carried off by the rays. In this way the presence of a slight positive charge on the active particles which diffuse from thorium may be explained.

Attempts to obtain this emanation or something similar to it from uranium, polonium, and radium have failed. Rutherford's specimens of radium and polonium were, however, not pure. S. Meyer and E. R. Schweidler[1] observed that when a radium barium carbonate prepared by M. and Mme. Curie was removed from a metallic cylinder within which it had been kept, the air within the cylinder retained its conductivity for some time. But radium salts prepared by Giesel did not show this. These facts, together with the induced radio-activity observed by M. and Mme. Curie, suggest that possibly some of the radium salts give off a vapor similar to that observed from thorium.

MAGNETIC DEFLECTION.

Elster and Geitel[2] observed that the discharge by Becquerel rays of an electrified body in a vacuum tube was retarded by a magnetic field. Two explanations at once suggest themselves: the effect may be due to the deflection of the rays by the magnetic field, or, as in the case of discharge by ultra-violet light, part of the ions may be deflected back on the charged body. Attempts by them to observe a direct magnetic deflection of the radium rays were at first failures. This failure was probably due to the nature of the salt used as well as the method. Later a magnetic deflection was observed almost simultaneously by S. Meyer and E. R. v. Schweidler,[3] Giesel,[4] and Becquerel.[5] It has since been verified by Elster and Geitel[6], Warburg[7] and M. and Mme Curie[8] and several others. In all cases the deflection is in the same direction as for kathode rays, *i. e.*, in the direction corresponding to the deflection of a negative current.

The deflection is not obtained with the rays from all the salts of radium and polonium. Meyer and Schweidler failed to find it with the rays from

[1] Physik. Ztschr., p. 209, Feb. 10, 1900.
[2] Wied. Ann. 69, p. 83.
[3] Physik. Ztschr., Nov. 25 and Dec. 2, 1899.
[4] Wied. Ann., 69, p. 834, Dec., 1899.
[5] C. R., 129, p. 996, Dec. 11, 1898.
[6] Verhandl. Deutsch. Phys. Ges., Leipzig, Jan. 5, 1900.
[7] Ibid.
[8] C. R., 130, pp. 73 and 76.

a radium barium carbonate and a polonium nitrate. Both Becquerel and M. and Mme. Curie failed to find any deflection of the rays from any of the polonium salts prepared by M. and Mme. Curie. Rays from some polonium prepared by Giesel have been deflected.[1] This has led to a classification by M. and Mme. Curie[2] of the rays under two heads, the rays deflectable by a magnetic field, and those not deflectable. Many salts of radium give off both kinds. This classification corresponds to that already given under the head of absorption. The more penetrating rays of radium are the deflectable ones, while the less penetrating ones are not deflectable. The rays from the polonium prepared by M. and Mme. Curie are not deflectable, and they do not contain any of the more penetrating type. M. and Mme. Curie[3] have found that the non-deflectable rays of radium behave like the rays from their polonium. As measured by the conductivity imparted to air the penetrating or deflectable rays of radium are a small fraction of the total radiation. However, the less penetrating rays are almost totally absorbed by 7 cm. of air, so that at even small distances from the source the penetrating rays are in excess. Debierne[4] has shown that the rays from actinium belong to the deflectable class. Thorium rays have not as yet been deflected.

Becquerel[5] has recently obtained a magnetic deflection of uranium rays. It has been thought that part at least of the radiation from uranium is due to the presence as an impurity of actinium. Becquerel attempted to remove the actinium from the uranium salt. This decreased the activity of the uranium and the foreign substance extracted was found to be active. As the radio activity of uranium was not entirely destroyed, Becquerel thinks that uranium has a radiation of its own. The deflectable and the more penetrating rays, β rays, of uranium are probably due to actinium.

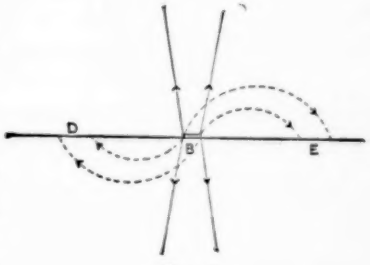

Fig. 1.

The usual method of observing the magnetic deflection is to place the radiant substance on a photographic plate or on a fluorescent screen. The radio-active salt is placed in a hole in a little block of lead so that the rays are emitted only in a direction perpendicular to the plate or screen. When the field is excited to about 2000 C. G. S. units the rays are

[1] Elster and Geitel, Meyer and Schweidler, and Giesel.
[2] C. R., 130, pp. 73 and 76.
[3] Ibid.
[4] C. R., 130, p. 906.
[5] C. R., 130, p. 1585, June 11, 1900.

deflected in a circular path and fall on the plate or screen on one side of the radio-active substance. As used by Meyer and v. Schweidler, the substance B (see figure) is placed below a fluorescent screen. With no magnetic field the rays travel rectilinearly away from B exciting luminosity only on a spot directly above B. When a uniform magnetic field, perpendicular to the plane of the figure and in direction away from the observer, is created, two luminous spots will appear, D and E. An opaque screen placed above B will cause the spot E to disappear. When placed below B it will affect D, or when placed below E no effect is observed. In this way the path of the rays is readily traced.

When the rays are perpendicular to a uniform field they move in arcs of circles, but when the direction is not perpendicular to the field, or the field is not uniform, the path is more complex. In all cases the action is similar to that observed with kathode rays. Becquerel found that when the direction of the rays was not perpendicular to the field the path became a spiral. If the field were not uniform the rays could be concentrated or focused by it.[1] For example, if the radium salt be placed on or near one pole face of an electromagnet of the horseshoe type and a screen placed near the opposite one, the diffuse illumination of the screen could be concentrated by the field to the part nearest the pole piece. This requires an electromagnet of rather small pole pieces.

These effects are all readily explained if we assume that the rays are, as is now generally conceded in the case of the kathode rays, small particles carrying negative charges.

Until the determination of the magnetic deflection of Becquerel rays, the known phenomena of these rays were almost identical with those of X-rays. The discovery of the magnetic deflection of Becquerel rays led Strutt[2] to make a further attempt to deflect X-rays. By carefully arranged apparatus he was able to assert that if there were a deflection, the radius of curvature of the path was greater than 19,800 cm., in a field of 3270 C.G.S. units. With this field the radius of curvature of Becquerel rays was about a centimeter.

If the deflectable Becquerel rays consist of rapidly-moving negatively charged particles, it may be shown that

$$m\frac{v^2}{\rho} = Hev$$

or

$$\frac{e}{m} = \frac{v}{H\rho},$$

where e/m is the ratio of the charge to the mass of the particle, v its velocity, H the strength of the magnetic field, and ρ the radius of curvature of the path of the rays. It has been observed by several that the rays

[1] Becquerel, C. R., 129, p. 912, also Meyer and v. Schweidler, Physik. Ztschr., 1, p. 113.
[2] Proc. Roy. Soc., 46, p. 75.

are not equally deflected. Becquerel[1] found that in the radiation from a single sample of radium the value of $H\rho$ varied from about 350 to nearly 3,000. As is evident, a magnetic spectrum of Becquerel rays is always produced with a source that gives such a non-homogeneous radiation. The values of $H\rho$ are of the same order of magnitude as in the case of kathode rays.

That different parts of this spectrum have different properties is readily shown by its penetrative power. Those rays which are deflected the most will penetrate only very light bodies or very thin sheets of paper and aluminium foil. For the portion of the spectrum corresponding to a small deflection the rays will penetrate thicker or denser metals. The penetrative power increases as the deflection decreases. Or for those rays for which $\frac{e}{mv}$ is smaller the penetration is greater. This is what would be expected if the difference in the rays is due to a difference of velocity of the charged particles, since the particle with the greater velocity is more penetrating and is also less deflected by the field. To observe this difference in absorption, Becquerel laid side by side on a photographic plate long narrow strips of the different metals. The direction of the strips was parallel to the direction of the dispersion. In this way it was easily shown that the thin strips of the lighter materials let through almost the entire spectrum, while the denser strips let through only the part deflected the least.

From Becquerel's observations may be deduced, at least approximately, that the amount of spectrum transmitted by different substances of the same thickness, follows the inverse order of their densities. This is in confirmation of the view that the difference in deflection is caused by a difference in velocity of the particles. Following this hypothesis of small particles, the non-deflectable or less penetrating rays are probably particles of much greater mass. Whether these particles are charged or not is not certainly known, as the deflection of larger particles may be so small as to have escaped detection.

Becquerel[2] found that an absorbing screen placed near the source permitted rays giving greater deflection to pass through than when the screen is placed farther from the source. Others[3] have noticed that the absorption of a screen increases with the distance from the source. This may be explained in two ways. The penetrating power of the rays seems to depend on their velocity. If the velocity is decreased by passage through the air then the rays have less penetrative power at greater distances from the source. Or, the apparent transmission may be

[1] C. R., 130, p. 372.
[2] C. R., 130, pp. 372 and 979.
[3] See C. R., 130, p. 979.

largely due, as some writers think, to a secondary radiation emitted by the screen. This secondary radiation may travel at a different velocity and may be deflected more than the incident beam.

Becquerel[1] tried in several ways to find out if the velocity was altered by transmission through air or other substances. Any change in velocity should be detected by a change in the magnetic deflection. Although unable to settle the question positively, as the experimental difficulties are rather great, he could detect no change in the velocity or rather in the ratio $\frac{e}{mv}$. Some experiments on this subject are misleading. Becquerel[2] obtained a magnetic deflection in a vacuum and then in air. Measurements showed them equal. But he protected his plates with black paper. As he has since pointed out, if the rays which penetrated the paper in a vacuum had their velocity diminished in air, their penetrative power would be decreased, and although deflected more the photographic plate would not show it as they could not then penetrate the paper. The great difficulty in determining any change in the velocity is due to the many different velocities present, and an inability to distinguish them. In this connection it may be stated that no change in the velocity of kathode rays has been observed when they have penetrated screens.

ELECTROSTATIC EFFECTS.

If the deflectable rays carry negative charges they should, as is the case with kathode rays, give negative charges to bodies which they strike, and should be deflected by an electrostatic field. At first[3] no such effects were obtained. As the rays make the surrounding air a conductor, any negative charge imparted to a body will be conducted off by the air. This conductivity of the air also makes a deflection of the rays by an electrical field difficult to observe, since the air being a conductor tends to serve as an electrostatic screen.

There seem but two ways open to detect the negative charge imparted to a body struck by the rays. If the body be enclosed by a very high vacuum it can then retain its negative charge. This may be varied by placing the radium salt in the vacuum, where it will accumulate a positive charge. The second method is to entirely enclose either the target or the radium itself in a solid dielectric like paraffin or ebonite. One side of this dielectric should be thin enough to permit the rays to traverse it. Using this latter method M. and Mme. Curie[4], with a sensitive electrometer, observed not only that the rays carried with them negative

[1] C. R., 130, p. 979.
[2] C. R., 130, p. 206.
[3] Becquerel, C. R., 129, pp. 1205 and 130, p. 206.
[4] C. R., 130, p. 647.

charges, but also that the rays by carrying away a negative charge left a positive charge on the radium. The rate at which a negative charge was carried off by the rays as measured in amperes was 4×10^{-12} per sq. cm. of the radium salt.

E. Dorn[1] was the first to obtain a deflection of Becquerel rays by an electrostatic field. The rays used were those from a bromide of barium and radium. Lenard[2] found that the excitation of a fluorescent screen by the impact of kathode rays could be either increased or decreased by an electric field parallel to the direction of the rays. When the field accelerated the charged particles the fluorescence was increased. Reversing the field produced a diminution. Dorn repeated this experiment, using radium rays instead of kathode rays, and obtained the same results as Lenard.

Becquerel[3] independently obtained an electrostatic deflection of the rays. Although he used an intense electrical field of about 10,000 volts per cm., the deflection observed on the photographic plate was only 4 mm. Hence it was necessary to use a very narrow beam of rays such as obtained through a narrow linear slit. In the path of this narrow beam was placed a thin screen, mica covered with tin, parallel to the linear source and edge on, so that its shadow on the plate was linear. By deflecting the beam at right angles to this shadow a broadening of it was obtained. As in the case of magnetic deflection it was observed that the rays were unequally deflected, again showing their composite character.

Knowing the field strength and the amount of the deflection the value of mv^2/e is obtained. Since mv/e is obtained from the magnetic deflection both the velocity and the ratio of charge to mass may be computed. The difficult thing is to identify in the two spectra the corresponding radiations. By observing the parts of the two spectra which seemed to show the same penetration he obtained the values for e/m and v,

$$\frac{e}{m} = 10^7, \quad v = 1.6 \times 10^{10} \text{ cm.}$$

The ratio of charge to mass and the velocity are therefore of the same order of magnitude as in the case of kathode rays. These values can be regarded only as approximations. The velocity according to the above figures is about one-half the velocity of light. The measurements of Dorn on the deflection by an electric field agree in magnitude with Becquerel's measurements. Using the value of the current obtained by M. and Mme. Curie, which is equal to Ne, where N is the number of particles given off

[1] Abh. d. Nat. Ges. zu Halle, March 11, 1900, also Physik. Ztschr., p. 337, May 5, 1900.

[2] Wied. Ann., 65, p. 509, 1898.

[3] C. R., 130, p. 809.

in one second, and the observed value of mv^2/e, $\frac{1}{2} Nmv^2$ or the energy per second of the radiation is obtained.

$Ne = 4.10^{-12}$ amperes or 4.10^{-13} C. G. S. and $mv^2/e = 2.57 \times 10^{13}$.

Then $\frac{1}{2} Nmv^2 = 5.1$ C. G. S. units. Or the energy emitted per second per square cm. is about five ten-millionths of a watt.

From the above ratio of e/m and the current the mass of the particles carried off in a second may be computed. This amounts to about a milligram in a thousand million years.

THEORIES.

Many theories have been suggested concerning the origin of the energy of the Becquerel radiation. Mme Curie[1] first suggested that the energy may be due to a very penetrating radiation hitherto unknown which could excite fluorescence in some substances. Sir William Crookes suggested in the Presidential address before the British Association in 1898 that in some way the energy might be obtained from the rapidly moving air particles. Elster and Geitel[2] took a salt of uranium into a deep mine, where it was protected by 850 meters of earth from any external radiations, and the salt was still active. When kept in a high vacuum the radiation was still emitted, so that the energy cannot be due to either a mechanical or chemical action of the air. They found that the impact of X-rays or kathode rays on the radiant substance produced no change in its radiation.

Elster and Geitel[3] suggested that the energy may come from an unstable molecule gradually passing over into a stable state. This idea was supported also by Behrendsen.[4] Until the discovery of the magnetic deflection of Becquerel rays many of the investigators had come to the conclusion that these rays were X-rays of feeble intensity. As the rays belonging to the deflectable group are now known to carry negative charges, they probably consist of small particles of matter, matter and electrical charges being, according to our experience, inseparable. According to the theory used to explain the Zeeman effect, each molecule has revolving around it at a high velocity one or more small satellites negatively charged. Measurements based on this theory have shown that the ratio of the charge to the mass, e/m, of a satellite is of the same order of magnitude as that obtained for the kathode ray particle or for the deflectable Becquerel rays. In the molecular groupings of the radioactive elements there may be conditions of instability such that some of

[1] C. R., 126, p. 1101.
[2] Wied. Ann., 69, p. 83, 1899.
[3] Beib., p. 443, 1899.
[4] Wied. Ann., 69, p. 220.

these satellites could be lost from their molecules, and moving off with their high velocity become the deflectable Becquerel rays.

The theory that Becquerel rays consist of extremely short ultra-violet light waves is now almost abandoned. In the case of the deflectable rays it is entirely dropped and it is believed that they, like kathode rays, are negatively charged particles of matter moving at extremely high velocity. Radiations of this character may differ among themselves in the size of the charge, the mass of the particles and their velocity. J. J. Thomson has shown that the ratio of charge to mass for the negatively charged particles in gases at low pressures is a constant. This together with results obtained from the Zeeman phenomena indicate that the ratio of charge to mass in these small particles is always a constant. If this is true it is the velocity which varies. The difference in penetration of Becquerel rays and kathode rays is then readily explained by a greater velocity for the Becquerel ray particle. The measurements of mv/e by Becquerel give values ranging approximately from 400 to 3000. The upper limit is higher than obtained by kathode rays and as it is the rays that give the larger values which are the more penetrating, it is safe to assume that the more penetrating rays have a greater velocity than kathode rays.

All results indicate that the atomic charge e is invariable and as in the case of the negative ion in the kathode ray or ultraviolet light discharge one infers that the mass m of the particle is much smaller than an atom, being only about one-thousanth of the size of the hydrogen atom or the ion found in electrolysis.

A theory of X-rays which is now gaining in popularity is that they are the small kathode ray particles after they have lost their charges. The absence of a charge accounts for the greater penetration. On this basis one might expect to obtain X-rays from radium rays. Villard[1] has detected the presence of such a radiation, an effect being obtained through 1 cm. of glass. This has as yet not been confirmed.

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[1] C. R., 130, p. 1010, April 9, and p. 1178, April 30, 1900.

THE PROBLEM OF THE STRESSES AND STRAINS IN A LONG ELASTIC HOLLOW CYLINDER SUBJECTED TO INTERNAL AND EXTERNAL PRESSURE, AND TO TENSION.

BY W. S. FRANKLIN.

INTRODUCTORY.

IN March, 1899, the writer came upon an unsatisfactory treatment of this problem in reading a well-known treatise upon Elasticity and the Strength of Materials. The unsatisfactory character of the treatment was due, in part, to unavoidable brevity and in part to what seemed to be erroneous statements concerning the relation of the formulas of Lamé, of Clavarino, and of Birnie, which formulas have been used in the designing of guns. The present writer, having some interest in the problem, worked it out in full as outlined below. The result of this solution is a pair of formulas (one for stresses the other for strains) which include the three above mentioned formulas as special cases. There is no reason to believe, however, that there is anything new in this present solution, although the solution given in Lamé's "*Leçons sur la Theorie Mathematique de l'Élasticité des Corps Solides*" is extremely brief, and no helpful references could be found in the Todhunter-Pearson *History*.

FUNDAMENTAL EQUATIONS.

Let P, Q and R be the principal pulls of the stress at a given point in the elastic cylinder and let p, q and r be the principal stretches of the strain at the same point. Then for any isotropic substance which conforms to Hooke's Law we have:

$$P = ap + bq + br \tag{1}$$

$$Q = bp + aq + br \tag{2}$$

$$R = bp + bq + ar \tag{3}$$

in which a and b are constants.

Statement of the Problem.

A long tube of inside radius ρ_i and outside radius ρ_{ii} is subjected to an internal pressure P', an external pressure P'' and a total end thrust T. The elastic constants a and b of the material are given and it is required to determine the stress and strain at each point throughout the material.

General Considerations and Notation.

The principal axes of the stress (and strain) are, at each point, *in the direction of the radius of the cylinder, in the direction of the axis of the cylinder, and tangential (perpendicular to the first two)* respectively. This is evident from considerations of symmetry, the tube being endless.

Consider an element of the material of the tube, distant x from the axis of the tube. Let P be the radial pull (force per unit area), Q the longitudinal pull, and R the tangential pull at the element; and let p, q, and r be the corresponding stretches at the element. It is evident that every portion of the tube is equally elongated so that q has the same value throughout the material of the tube. Considerations of symmetry show that p, r, P and R are the same all along the tube at a given distance from the axis, that is they are functions of x alone. It will appear later that Q has the some value throughout the material of the tube.

Basis of Solution.

The problem is to be solved with the help of the equations (1), (2) and (3), using the conditions of internal equilibrium, the condition of continuity of strain (and stress), and the boundary conditions which arise from prescribed external and internal pressure and prescribed total end thrust.

The Condition of Equilibrium.

The condition of equilibrium (internal) gives

$$Pdx + xdP = Rdx \tag{4}$$

The Condition of Continuity.

The condition of continuity gives

$$pdx = rdx + xdr \tag{5}$$

INTERNAL AND EXTERNAL BOUNDARY CONDITIONS.

At the inner surface of the tube the radial pull P is equal to the inside pressure P' and at the outer surface of the tube the radial pull P is equal to the outside pressure P''.

Remark: Considered as pulls P' and P'' are of course *negative*.

TOTAL END THRUST.

The distribution of the end thrust over the section of the tube (value of Q at each point) will be determined later. This determination is subject to the condition of a prescribed total end thrust T. The relation between T and Q is:

$$T = 2\pi \int_{\rho_i}^{\rho_{ii}} Qx\,dx \tag{6}$$

SOLUTION OF EQUATION (4), ETC.

Let

$$Px = Y \text{ or } P = \frac{Y}{x}.$$

Then from equation (4)

$$R = \frac{dY}{dx}.$$

Substituting these values of P and R and the value of p from equation (5) in equations (1), (2) and (3), we have:

$$\frac{Y}{x} = a\left(r + x\frac{dr}{dx}\right) + bq + br \tag{7}$$

$$Q = b\left(r + x\frac{dr}{dx}\right) + aq + br \tag{8}$$

$$\frac{dY}{dx} = b\left(r + x\frac{dr}{dx}\right) + bq + ar. \tag{9}$$

Substituting the value of Q from (8) in (6) we have after reducing

$$T = 2\pi \int_{\rho_i}^{\rho_{ii}} \frac{d(brx^2)}{dx} \cdot dx + 2\pi \int_{\rho_i}^{\rho_{ii}} aqx\,dx$$

or, since b, a and q are constant:

$$T = 2\pi b(r_{ii}\rho_{ii}^2 - r_i\rho_i^2) + \pi aq(\rho_{ii}^2 - \rho_i^2) \tag{10}$$

in which $\rho_{,,}$ and $\rho_{,}$ are the outer and inner radii of the tube, and $r_{,,}$ and $r_{,}$ are the values of the stretch r (circumferential) at outside and inside of tube respectively.

Remark: Equation (10) shows that the length of the tube will change (q other than zero) when T is zero.

Solution of Equations (7), (8), and (9), etc.

Differentiating equation (7) with respect to x and substituting the resulting value of $\frac{dY}{dx}$ in equation (9) we have

$$x\frac{d^2r}{dx^2} + 3\frac{dr}{dx} = 0, \tag{11}$$

whence by integration

$$r = C' - \frac{C''}{2x^2} \tag{12}$$

in which C' and C'' are constants.

Substituting this value of r in equation (5) we have

$$p = C' + \frac{C''}{2x^2} \tag{13}$$

Substituting the value of r from (12) in (10) we have

$$T = 2\pi bC'(\rho_{,,}^2 - \rho_{,}^2) + \pi aq(\rho_{,,}^2 - \rho_{,}^2)$$

or

$$q = \frac{T}{\pi a(\rho_{,,}^2 - \rho_{,}^2)} - \frac{2bC'}{a} \tag{14}$$

Remark: Equations (12), (13) and (14) contain the general solution of our problem (since P, Q and R are given by equations (1), (2) and (3) in terms of p, q and r) and it only remains to determine the constants C' and C''. For this purpose we need to substitute r, p and q from (12), (13) and (14) in (1). The resulting expression for P is general. In this expression put $P = P'$ and $x = \rho_{,}$ and then put $P = P''$ and $x = \rho_{,,}$. The two equations thus obtained may be solved for C' and C''. In this manner we obtain

$$C'' = \frac{2(P' - P'')\rho_i^2\rho_{ii}^2}{(a-b)(\rho_{ii}^2 - \rho_i^2)}, \tag{15}$$

and

$$C' = \frac{\pi a(P'\rho_i^2 - P''\rho_{ii}^2) + bT}{\pi a(\rho_{ii}^2 - \rho_i^2)\left(a + b - \frac{2b^2}{a}\right)}. \tag{16}$$

FINAL RESULTS.

Using equations (15) and (16) in conjunction with (12) (13) and (14) we have:

$$p = \frac{\pi a(P''\rho_{ii}^2 - P'\rho_i^2) - bT}{\pi a(\rho_{ii}^2 - \rho_i^2)\left(a + b - \frac{2b^2}{a}\right)} + \frac{(P' - P'')\rho_i^2\rho_{ii}^2}{x^2(a-b)(\rho_{ii}^2 - \rho_i^2)} \tag{17}$$

$$q = \frac{T}{\pi a(\rho_{ii}^2 - \rho_i^2)} - \frac{2\pi ab(P''\rho_{ii}^2 - P'\rho_i^2) - b^2T}{\pi a^2(\rho_{ii}^2 - \rho_i^2)\left(a + b - \frac{2b^2}{a}\right)} \tag{18}$$

$$r = \frac{\pi a(P''\rho_{ii}^2 - P'\rho_i^2) - bT}{\pi a(\rho_{ii}^2 - \rho_i^2)\left(a + b - \frac{2b^2}{a}\right)} - \frac{(P' - P'')\rho_i^2\rho_{ii}^2}{x^2(a-b)(\rho_{ii}^2 - \rho_i^2)} \tag{19}$$

Substituting these values of p, q and r in equations (1), (2) and (3) we have:

$$P = \frac{P''\rho_{ii}^2 - P'\rho_i^2}{\rho_{ii}^2 - \rho_i^2} + \frac{(P' - P'')\rho_i^2\rho_{ii}^2}{x^2(\rho_{ii}^2 - \rho_i^2)} \tag{20}$$

$$Q = \frac{T}{\pi(\rho_{ii}^2 - \rho_i^2)} \tag{21}$$

$$R = \frac{P''\rho_{ii}^2 - P'\rho_i^2}{\rho_{ii}^2 - \rho_i^2} - \frac{(P' - P'')\rho_i^2\rho_{ii}^2}{x^2(\rho_{ii}^2 - \rho_i^2)} \tag{22}$$

These equations (17) to (22) involve all the formulas hitherto published in connection with the problem under discussion.

A UNIVERSAL LAMP-SUPPORT FOR THE PHOTOMETRY OF GLOW-LAMPS.

By Clayton H. Sharp.

THE problem of determining the mean spherical intensity of glow-lamps by a method at once exact, simple and convenient has never received a satisfactory solution. The methods which are in use require a long series of measurements, and the greater the accuracy which is demanded, the more numerous (within limits, of course) must the measurements be. On account of this difficulty the common technical practice has been to deduce the mean spherical intensity from the intensity measured in a certain direction, using a reduction-factor which holds, of course, only for the type of lamp in question, and which represents a mean value for this type. While this method yields average results which are satisfactory, it cannot be maintained that the value so obtained for any single lamp can make claim to any large degree of trustworthiness.

In order to make the matter entirely clear let us consider for a moment the theory on which the determination of mean spherical intensity is based. Suppose the source of light to be placed at the center of a sphere of unit radius. The mean spherical intensity is equal to the total luminous flux Φ through this sphere divided by the area of the sphere, that is $I_m = \frac{1}{4\pi}\Phi$. If we take a zone of width $\delta\theta$ cut on the sphere by two planes perpendicular to the axis of the lamp, and if this zone lies θ radins from the intersection of the sphere by the axis of the lamp, we have for the flux through this zone,

$$\delta\Phi = 2\pi I_\theta \sin\theta\delta\theta$$

in which I_θ is the mean luminous intensity in the direction of the entire zone; that is, it is the mean intensity for the polar-distance θ.

It follows, therefore, that

$$\Phi = 2\pi \sum_{\theta=0}^{\theta=\pi} I_\theta \sin\theta\delta\theta$$

and

$$I_m = \tfrac{1}{2} \sum_{\theta=0}^{\theta=\pi} I_\theta \sin\theta\delta\theta.$$

The value of I_m can therefore be determined as soon as one knows the various values of I_θ. With the ordinary method, however, the determination of I_θ is a rather tedious process, since one must make for each value of θ a series of measurements along the entire length of the zone.

As regards the determination of the mean horizontal intensity of a glow-lamp, the state of affairs is quite different, since there are two perfectly good methods for determining the quantity by means of a single photometer setting. These are Crova's method of the rotating lamp, and the method of the two rotating mirrors used by Dr. Liebenthal[1] in the Physikalische-technische Reichsanstalt in Charlottenburg. The accuracy of the first method has been amply proved by Matthews[2] who obtained concordant results for measurements made by this method and also by the ordinary method of the horizontal distribution of an old-fashioned Maxim lamp giving a very irregular distribution of intensity.

It naturally occurs to one to apply this simple method to the measurement of mean spherical intensity by inclining the rotating lamp at various angles with respect to the photometer and so, by means of one photometer-setting, to determine the mean intensity in the zone in question.[3] The mechanical difficulties which stand in the way of this procedure need scarcely to be pointed out. It would be much easier to place a mirror in the direction in question and, by means of it, to send the beam of light from the rotating lamp along the photometer-bar. The amplification of this idea has lead me to the design of the instrument which is here to be described. Professor Wiener has very kindly had the instrument constructed after my drawings for the Physical Institute of the Uni-

[1] Zeitschrift für Instrumentenkunde, Vol. XIX., p. 193, 1899.

[2] PHYSICAL REVIEW, Vol. VI., p. 55, 1898.

[3] Since writing the above I have been informed that this method is actually in use in a large lamp factory in America.

versity of Leipzig in the instrument works of Dr. Emil Stoehorer & Son, in Leipzig.

The lamp is fixed to a vertical axis and is turned at the rate of four or five revolutions per second by means of a cord running on a pulley at the lower end of the axis. The current is brought in by means of the two carefully insulated brushes K, K'. The light sent out by the lamp in two directions 180° apart is received by two

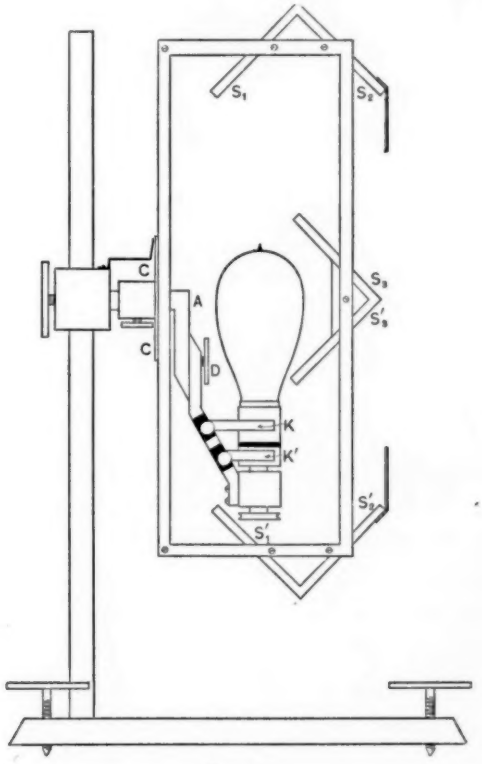

Fig. 1.

sets of mirrors S_1, S_2, S_3 and S_1', S_2', S_3', and, after triple reflection, is sent along the photometer-bar. These mirrors are set between two rectangular frames which can be adjusted at any angular position on a horizontal axis A, the prolongation of which passes through the mid-point of the lamp filament. The inclination of the frames with respect to the vertical lines can be read from the divided circle C to which they are affixed. The lower part of the lamp-holder is

adjustable in a vertical direction so that the filament of a lamp of any size can be brought into the proper position with respect to the axis A. D is the screw by means of which this part is clamped in place.

The whole arrangement is shown in Fig. 2. For the sake of convenience in driving the lamp, a special counter-shaft is attached to the instrument as Fig. 2 shows. A steel shaft is fixed in a ver-

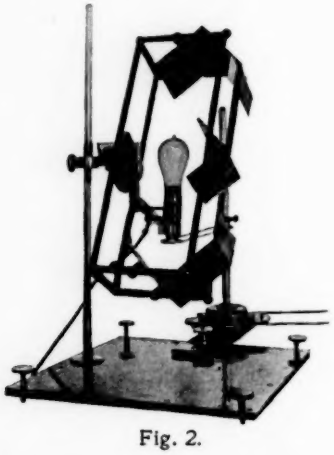

Fig. 2.

tical position in a metal plate which can be fastened by a clamping screw to either side of the base of the instrument, and which is slotted so that the driving cord can be tightened. A brass tube fitted with steel ring bearings runs on this shaft and carries a large pulley for the cord from the motor to a small one for that running on the lamp-pulley. The position of both pulleys on the tube is adjustable according to the position of the motor and the height of the lamp-pulley above the base of the instrument. The other, less important details of the construction of the apparatus will be understood directly from a study of the figures.

It is at once clear that when one looks from where the photometer is placed into the mirror S_3 and S_3' one sees two images of diametrically opposite sides of the lamp. It follows therefore that when the lamp is rotating and the mirrors are set at an angle θ, one gets as the result of a photometer setting the sum of the mean intensities in two zones θ and $\theta + \pi$, diminished, of course, by the amount which is lost by absorption in the mirrors. Therefore, one

needs only to make a sufficient number of measurements between $\theta = 0$ and $\theta = 90°$ to get all the data required for the computation of the mean spherical intensity of the lamp.

The results of such a set of measurements made on a lamp with a single-loop filament are shown plotted in polar coördinates in Fig. 3.

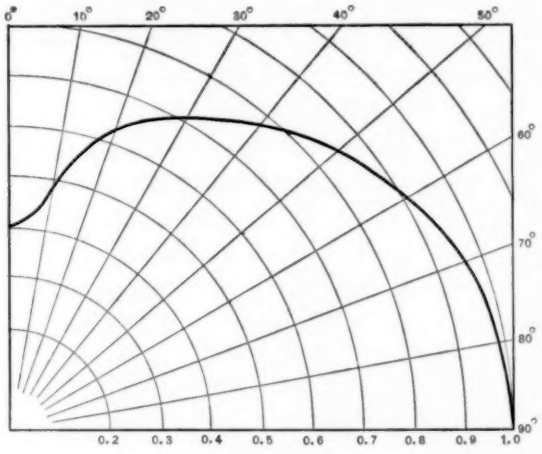

Fig. 3.

From this curve one could deduce the mean spherical intensity by means of the purely graphical method of Rousseau [1] or the method of Liebenthal [2] which is, in principle, quite like that of Rousseau.

If one desires to dispense with graphical methods, one can compute the value of I_m as follows: The unit sphere is divided into zones of such width that one may assume that the mean intensity for the whole width of the zone is given, to the required degree of approximation, by a measurement made in the middle of the zone. Then, for the zone whose boundaries are $\theta = 1$ and $\theta = 2$,

$$\partial \Phi_{1,2} = 2\pi I_\theta \int_1^2 \sin\theta d\theta = 2\pi I_\theta (\cos\theta_1 - \cos\theta_2).$$

Therefore,

$$I_m = \tfrac{1}{2}\{(\cos\theta_1 - \cos\theta_2) I_{1,2} + (\cos\theta_2 - \cos\theta_3) I_{2,3} + \cdots\}_{\theta=0}^{\theta=\pi}.$$

In case $I_{1,2}$, $I_{2,3}$, etc., refer to measurements made with this apparatus, we have,

[1] Palaz. Photometry, Petterson's tr., p. 20.

[2] Elektrotechnische Zeitschrift, Vol. X., p. 337, 1889.

$$I_m = \{(\cos\theta_1 - \cos\theta_2)I_{1,2} + (\cos\theta_2 - \cos\theta_3)I_{2,3} + \cdots\}_{\theta=0}^{\theta=\frac{1}{2}\pi}.$$

In order to make the numerical computation of I_m more convenient I have computed tables for four different cases, namely for zones 10°, 15°, 18° and 30° wide, beginning and ending the measurements in each case at 0° and at 90° respectively. In these tables, θ is the direction in which the intensity is measured, and κ is the constant with which I_θ is to be multiplied. Designating by r the coefficient of reflection of the mirrors, we have as a working formula,

$$I_m = r\{\kappa_1 I_1 + \kappa_2 I_2 + \cdots\}_{\theta=0}^{\theta=90°}.$$

A 30° zones.		B 18° zones.		C 15° zones.		D 10° zones.	
θ	κ	θ	κ	θ	κ	θ	κ
0°	0.034	0°	0.012	0°	0.009	0°	0.004
30	.259	18	.097	15	.067	10	.030
60	.448	36	.184	30	.131	20	.060
90	.259	54	.253	45	.184	30	.087
		72	.298	60	.226	40	.112
		90	.156	75	.253	50	.133
				90	.1305	60	.151
						70	.164
						80	.172
						90	.087

In order to get at a basis for comparison I have computed I_m for the lamp mentioned above with the help of tables A, B, C and D, that is from 4, 6, 7 and 10 measurements, with the following results, in which I_m is exposed as a fractional part of the mean horizontal intensity.

Width of zones.	Number of Measurements.	I_m
30°	4	0.868
18	6	.863
15	7	.864
10	10	.8683

From the above results one may conclude that the result obtained from measurements in only four directions can not well, in any similar case, be far wrong. If we assume that the ordinary method had been followed and that measurements had been made in twelve dif-

ferent positions 30° apart in each zone, the number of measurements would increase from 4 to 74.

The speed of rotation of the lamp is without influence on the result so long as it is not so slow that too strong a flickering is noticed on the photometer disc. If the speed is too high, the filament may be thrown from its position and the lamp endangered.

As to the length of the path which the light must traverse within the apparatus, we need only to notice that this is equal to the distance between the apexes of the two angles which the mirrors S_1, S_2 and S_1', S_2' enclose; that is taking the apex of the angle between S_3 and S_3' as the line of reference. The equivalent length of the path in the glass of the mirrors can be computed, assuming the value 1.5 for the index of refraction of the glass.

In order to determine the reflecting power of the mirrors, the mean horizontal intensity is measured with and without the mirrors, that is to say, one measures the rotating lamp with the mirror-frame horizontal, and again with the front mirrors S_3 and S_3' removed. The reflecting power can at once be computed from these data. For the present instrument this is 71.0%, that is, 10.8% per mirror.

It may be pointed out that this lamp standard may be used for making all the other usual measurements on glow-lamps. To measure the vertical distribution of intensity, one set of mirrors is covered over and the stationary lamp is viewed through the other set in the various positions between 0° and 180°. In order to make it possible to measure the horizontal distribution of intensity, the little pulley beneath the lamp is divided in 10° divisions. One can therefore properly designate this apparatus as a universal lamp-support for glow-lamp photometry.

I wish also to point out the fact that a single set of mirrors like those described above would be employed in the photometry of arc-lamps as Krüss[1] has already done in gas-flame photometry. As a substitute for the ordinary cumbersome apparatus, this arrangement would possess decided advantages. Whether the principle of the rotating lamp would not also be advantageouly employed in arc-lamp photometry, would be decided by a simple experiment which the means at present at my disposal do not permit me to carry out.

PHYSICAL INSTITUTE OF THE UNIVERSITY OF LEIPZIG, June, 1900.

[1] Journal für Gasbeleuchtung, Vol. 41, p. 4, 1898.

NOTES.

Thomas Preston.—Thomas Preston, whose death occurred in Dublin, March 7, 1900, was born in County Armagh, Ireland, in 1860. He was a graduate of Trinity College, Dublin, and also of the Royal University of Ireland, having received from the latter institution the degree of Doctor of Science. At the time of his death he held a fellowship in the Royal University. He was elected a Fellow of the Royal Society in 1898.

It is probably through his "Theory of Light" that Preston is most widely known. This well-known text-book, which first appeared in 1890, was from the first received with universal favor. During the past ten years it has probably been used as an introduction to the study of optical theory by the great majority of advanced students of physics, both in Great Britain and America. Preston's "Theory of Heat" appeared in 1895 and has also been very favorably received.

Since the completion of his two text-books Preston had devoted his time more largely than before to scientific investigation. His earlier work had to do with problems connected with the theoretical side of the subjects of light and heat. We may mention, for example, his papers on "The Continuity of Isothermal Transformation from the Liquid to the Gaseous State,"[1] and the "General Extension of Fourier's Theorem."[2] But his more recent work, and also his most important work, namely, that dealing with the Zeemann effect, was chiefly experimental. Preston was the first to obtain photographs of the Zeemann doublets and triplets suitable for enlargement and lithographic reproduction. All who have followed the development of the Zeemann phenomena will remember with pleasure the plate accompanying Preston's first article on the subject in 1898.[3] In this article he called attention also, for the first time, to the more complicated modifications of the spectral lines produced by a magnetic field, namely, the quartet and sextet types.[4]

For his work in connection with the Zeemann effect Preston was recently awarded the Boyle medal of the Royal Dublin Society. E. M.

American Association for the Advancement of Science.—The forty-ninth meeting of the association was held in New York City, June 23–30, 1900. The early date of the meeting was adopted in order to make it possible for those contemplating a visit to the Paris Exposition

[1] Philosophical Magazine, 42, 231, 1896.

[2] *Ibid.*, 43, 281, 1897.

[3] Philosophical Magazine, 45, 325, 1898.

[4] Indications of a quartet type had, I believe, been previously obtained by Cornu.

to attend the meeting of the American Association before sailing. The same consideration was influential in deciding the place of the meeting. If we may judge by the attendance, which was larger than the average of recent years, the temporary change in the time of the meeting was received with general satisfaction. The fact that the date conflicted with that of the commencement exercises at several of the New England universities is however much to be regretted. In accordance with previous custom the next meeting will be held in the month of August.

For Section B the meeting was especially significant on account of the coöperation of the American Physical Society. The sessions of Section B and of the Physical Society were held on alternate days. But although the programs were kept separate, there was little else to distinguish the two. The holding of such a joint meeting, for the first time in the history of the Section B, was very properly regarded as an experiment. It is to be hoped that its undoubted success will lead to the permanent enrollment of the Physical Society among the numerous organizations already affiliated with the Association. The great increase in the scientific activity of our American physicists has now made the existence of two societies not only possible, but desirable. Certainly the coöperation of the two societies can scarcely fail to be of mutual benefit.

An important step as regards the general policy of the Association was taken by the Council in deciding to send *Science* free of charge during the coming year to all members of the Association. In a sense, *Science* will become the official organ of the American Association, in which its announcements and proceedings will be promptly published. It is hoped that this action will tend to increase the membership of the Association and increase its usefulness. If the results justify this expectation the policy will be continued. The annual volume of proceedings will be published as usual.

The program, while not so crowded as has often been the case in recent years, contained as many papers as could be properly treated in the time available. A brief discussion was possible in all cases, and the feeling of hurry, so conspicuous at the Boston meeting, was happily absent. But still more time for discussion is much to be desired. Sessions were held up to the close of the last day of the meeting, with the attendance almost as large at the last session as at the first.

In addition to the address of Vice-President Merritt on Kathode Rays and some Related Phenomena, the program of Section B included twenty-five papers, a list of which follows:

Temperature Effects on a Tuning-fork, John O. Reed and E. C. Woodruff; Some Lecture-room Methods in the Elementary Theory of Elasticity, W. S. Franklin; Velocity of Ions in the Electric Arc, C. D. Child; An Observation Upon the Surface Viscosity of Mercury, William

A. Anthony ; Note on the Flow of Energy Around a Conducting Screen Near a Current Sheet, W. S. Franklin ; A new Theory of the Electromagnetic Rotation of Light, Reginald A. Fessenden ; Application of the Schlieren Methods to the Microscope, R. W. Wood ; Photography of Sound Waves, R. W. Wood ; Copper Saving in the Joint Transmission of Direct and Alternating Currents, Frederick Bedell ; On the Theory of the Coherer, K. E. Guthe and A. Trowbridge ; The Surface-tension of Water Above 100° C., Charles Tobias Knipp ; The Effect Upon the Persistence of Vision of Exposing the Eye to Light of Various Wave-Lengths, Frank Allen ; A Method of Measuring Surface-Tension, James S. Stevens ; Notes on the Use of the Capillary Electrometer, A. D. Cole ; On the Visible Radiation From Carbon, Edward L. Nichols ; On the Development of Kathode Rays by Ultra-Violet Light, Ernest Merritt and O. M. Stewart ; Diffusion of Light, Edward Atkinson ; A Method for Measuring Surface Tension, S. Stevens ; The Percentage Bridge and its Applications, Herschel C. Parker ; On the Energy of the Cathode Rays, Walter G. Cady ; Power Curves Drawn from Alternating Current Circuits, Edward B. Rosa ; The Nature of Sound, E. M. Souveille ; Photographs of Electric Phenomena, T. B. Kinraide ; Circuit-Breakers and Induction Coils, Reginald A. Fessenden ; Some Experiments in Electric Lighting, Reginald A. Fessenden.

The following papers, fifteen in number, were read before the Physical Society :

The Anomalous Dispersion of Cyanine, R. W. Wood and C. E. Magnusson ; The Optical Properties of Thin Carbon Films, R. W. Wood ; A Mica Echelon Grating, R. W. Wood ; False Spectra from the Rowland Concave Grating, Theodore Lyman ; The Zeemann Effect, H. M. Reese ; Electrical Absorption in Condensers, L. M. Potts ; Polarization of the Solar Corona, N. E. Dorsey ; A Comparison of the Brightness of Prisms and Gratings in Spectrum Work, N. E. Dorsey ; Preliminary Tests on the Efficiency of the Acetylene Flame as a Means of Illumination, E. L. Nichols ; On the Characteristic Equation of Water, A. D. Risteen ; Some Simple Apparatus for the Study of Aerial Vibrations, F. L. Tufts ; The Use of the Bicycle Wheel in Illustrating the Principles of the Gyroscope, C. T. Knipp ; The Effect of Solid Dielectrics in the Production of Electrical Sparks, W. J. Humphreys ; Magnetic Observations on the Day of Eclipse, May 28, 1900, L. A. Bauer ; A Method of Obtaining Brilliancy of Concave Grating Spectra, W. J. Humphreys.

The next meeeting will be held in Denver, August 24–31, 1901, under the presidency of Chas. S. Minot. The officers of Section B for the Denver meeting are : Vice-President, D. B. Brace, Lincoln, Neb. ; Secretaty, J. O. Reed, Ann Arbor, Mich.

NEW BOOKS.

Optical Activity and Chemical Composition. By DR. H. LANDOLT, translated by JOHN MCCRAE, Ph.D. London and New York, Whittaker & Co., 1899. 16mo. Pp. 158.

In the original German this small book constitutes the eighth chapter of the first volume of Graham-Otto's "Lehrbuch der Chemie." The translator has greatly enhanced its value by introducing notes on several important investigations of which the results have appeared in the literature since the middle of the year 1897.

The main object of the book is to point out, by means of numerous illustrative examples, the connection between the phenomenon of circular polarization, as manifested by many organic compounds, and certain theories—chiefly stereochemical—as to the structure of the molecules of these substances. In order to fully appreciate the validity of the course of reasoning pursued one should read the work in its entirety, for much of the evidence is cumulative. It may be said, moreover, that the literary style is so simple and direct as to make it scarcely an effort to read. A more available summation of the results of recent research in this line is hardly conceivable.

An idea of the uses which the book is fitted to serve may perhaps be best gained by a few statements of detail. Apparatus for measuring circular polarization is not described. A list of all known circular-polarizing crystals is given, together with the crystal-symmetry of each and the amount of rotation of the D line. The 700 or more substances which are optically active in solution or in fluid condition are classified in 30 groups. The names of nearly two hundred of these substances are mentioned in the statement of the thirty groups, but no data are here given as to the *amount* of rotation. The meaning of specific rotation is explained and illustrated by examples. Many cases of the variation of specific rotation are cited. These variations are attributable to change of concentration, to difference in temperature, to change of solvent, to inactive substances in the solution, or to changes which take place on allowing the solution to stand for a time. The influence of inactive substances in the solution with the active is in some cases so remarkable that it may not be amiss to quote one example here. Ammonium molybdate, under conditions carefully stated in the text, causes the rotary power of malic acid to increase from 0.2° to 5.32°, but on further addition of the molybdate the amount of rotation decreases, passes through

zero, and then goes up to a maximum of 72.8° in the opposite sense! When the last point is reached there are two molecules of malic acid in the solution to one of molybdate.

The second (and largest) part of the book deals with the "connection between the Rotatory Power and the Chemical Composition of Carbon Compounds." This is in the main stereochemistry, dealing, among other things, with the possible number of active isomers and the methods of resolving "racemic" compounds into their active components or "antipodes." Many of the facts adduced are extremely interesting merely as matters of general information.

Part three is devoted to the "Connection between Degree of Rotation and Chemical Constitution." One feature of this final chapter is the attempt to show a dependence of the rotatory power on the masses of the four radicles which are united to the asymmetric carbon atom.

In conlusion, the book may be commended as an unusually clear, suggestive, and up-to-date exposition of the subject in hand.

A. C. GILL.

A Brief History of Mathematics. An Authorized Translation of Dr. Karl Fink's Geschichte der Elementar-Mathematik. By W. W. BEMAN and D. E. SMITH. Chicago, The Open Court Publishing Company, 1900. Pp. xii + 333.

While there is no extensive history of mathematics in the English language, such as Marie's in French and Cantor's in German, yet a number of brief histories have appeared in recent years. The principal ones of these are: Ball, A Short History of Mathematics, 1888; Cajori, A History of Mathematics, 1895; Cajori, A History of Elementary Mathematics, 1896. The present work differs from all of these in arrangement, giving the history of each of the elementary subjects, arithmetic, algebra, geometry and trigonometry separately. It differs still more in the choice of matter, omitting biography entirely and referring the reader to a brief table in the appendix or to the encyclopedias.

Fink's history is a somewhat hasty compilation from the larger works. Cantor points out a large number of errors in his review published in *Zeitschrift für Mathematik und Physik*, vol. 36, 1891, pp. 75–77. The translators have corrected a number of unquestionable errors and added occasional references. They have also rewritten the biographical notes, so that the translated work seems much more valuable to the teacher than the original. While the style is not a fluent one yet the work is quite readable and it seems to be unusually free from typographical errors.

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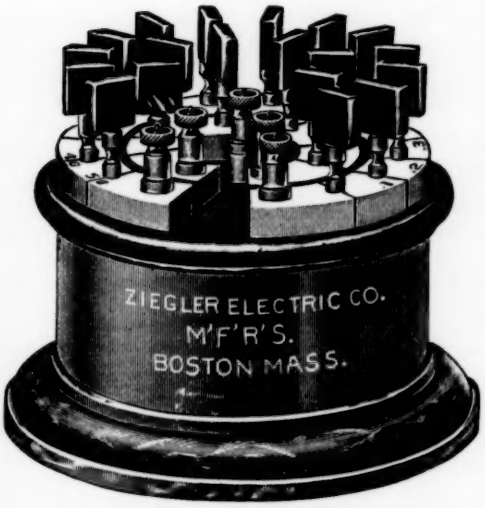

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